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PRELIMINARY EXAMINATION OF THE POTENTIAL OF GEOPOLYMERS FOR USE IN MINE TAILING MANAGEMENT

FINAL REPORT

BY

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Work on this project was conducted under the auspices of the Department of Energy, Mines and Resources

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November 20, 1987

Mr. G.M. Ritcey
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Energy, Mines and Resources Canada
555 Booth Street
Ottawa, Ontario
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Dear Mr. Ritcey:

Re: Preliminary Examination Of The Potential Of
Geopolymers For Use In Mine Tailing Management

Enclosed are ten (10) copies of Comcor Waste Management Consultants' (Comcor) final report entitled "Preliminary Examination Of The Potential Of Geopolymers For Use In Mine Tailing Management." This report was prepared under the auspices of the Department of Energy, Mines and Resources (EMR), DSS file No. 04SQ-23440-6-9195. These reports fulfill Comcor's contractual obligation under DSS Contract No. 23440-6-9195/01-SQ to EMR.

It was a pleasure to work with yourself and the Ontario Research Foundation on this project. While there are still numerous questions to be answered on the geopolymer technology, it is possible that this technology may find an application in the future for mine tailings management and disposal.

Please feel free to contact us if you should have any questions or comments concerning the report.

Yours truly,

COMCOR WASTE MANAGEMENT CONSULTANTS

Walter Graziani

Walter Graziani, P. Eng.
President

WMG/mg

Enclosures

EXECUTIVE SUMMARY

Comcor Waste Management Consultants, with the Ontario Research Foundation as subcontractor, have conducted a preliminary examination of the potential of utilizing geopolymers for the stabilization and solidification of mine tailings.

Four different types of mine tailings were tested. These were: high sulphidic base metal, high sulphidic coal, potash and uranium.

Tests were conducted to discover whether hazardous or toxic components would leach out of the treated tailings. Tests were also conducted to establish hydraulic conductivities and compressive strength.

The results demonstrated that tailing samples solidify with the addition of geopolymer and aggregate to the samples. Additionally, it was determined that there is a potential for locking the toxic and hazardous components into the geopolymerized matrix; however, this has not been proven conclusively.

Geopolymers show potential for application in mine tailings management; however, it is recommended that extensive additional bench scale laboratory test work and office studies be conducted prior to its use in large scale field tests or actual mine tailings management schemes.

SOMMAIRE EXECUTIF

Comcor Waste Management Consultants, avec L'Ontario Research Foundation comme sous-entrepreneur, ont dirigé une étude préliminaire sur la possibilité d'utiliser les géopolymères pour la stabilisation et la solidification des déchets miniers.

Ils ont analysé quatre types différents de déchets miniers: du métal de base fort en sulfure, du charbon fort en sulfure, de la potasse et de l'uranium.

Ils ont fait des analyses pour découvrir si des composants toxiques ou hasardeux peuvent s'échapper de ces déchets miniers traités. Des analyses ont aussi été conduites pour établir la conductivité hydraulique et la force de compression.

Les résultats ont démontré que les échantillons de déchets miniers se solidifient avec l'addition de géopolymère et s'aggrègent aux échantillons. En plus, ils ont déterminé qu'il y a possibilité d'enfermer les composants toxiques et hasardeux dans la matrice géopolymérisée; cependant, cette preuve n'a pas été concluante.

L'application des géopolymères dans l'exploitation des déchets miniers présente certaines possibilités; cependant, il est recommandé que de nouveaux travaux approfondis d'analyse en laboratoire soient conduits ainsi que des études de bureau avant son utilisation en grand dans les essais sur les terrains ou d'un projet actuel d'exploitation de déchets miniers.

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1.0 INTRODUCTION

Comcor Waste Management Consultants (Comcor) were contracted by Supply and Services Canada under contract number 23440-6-9195/01-SQ to examine the potential of geopolymers as an additive to mine tailings.

Ontario Research Foundation (ORF) acted as subcontractor to Comcor and was responsible for the design and implementation of the laboratory test program. The laboratory test program was approved by G.M. Ritcey of the Canada Centre for Mineral and Energy Technology (CANMET). Dr. J. Davidovits of Barry University, Florida, a noted specialist in geopolymer technology and the holder of several patents for geopolymers, provided expertise in geopolymer formulation to ORF.

The intent of this study was to, very preliminarily, examine the potential of utilizing geopolymers for the stabilization and solidification of mine tailings.

The stabilization of a waste material generally refers to a process or method that will convert any toxic or hazardous components in the waste into a chemical form that is resistant to leaching. That is, the toxic or hazardous components are locked into the waste mass. The solidification of a waste material, however, refers to the altering of a liquid or semi-solid waste into a cohesive solid. Often, solidification of waste also results in the stabilization of the waste and vice versa.

Geopolymers and geopolymer technology are described in detail in the ORF report enclosed in Appendix 1. Simply, a geopolymer should act like a concrete or cement and bond the tailings together into a

solidified mass. Ideally, any hazardous constituents would be locked (stabilized) into the solidified mass and not leach out.

Similar to cement, geopolymers require an aggregate to form a hard final product. It is hoped that mine tailings can replace the aggregate required. However, it is anticipated that some aggregate may be necessary to maintain a chemical balance.

what % ← page 4 says 50% sand.

2.0 TAILING SAMPLE TESTS

2.1 Tailing Samples Description and Source

The initial work program called for the testing of three (3) different types of tailings; namely, uranium, high sulphidic base metal and high sulphidic coal. At the request of G.M. Ritcey (CANMET), a potash tailing sample was included in the testing.

The four samples were obtained from the following locations:

1. Base metal - abandoned Kam Kotia Mine near Timmins, Ontario.

2. Coal - Hinton Mines, Alberta.

3. Uranium - Mid-West Mines, Saskatchewan.

4. Potash - Potash Corporation of Saskatchewan, Saskatchewan.

An additional uranium tailing sample was initially selected from Key Lake Mines, Saskatchewan; however, due to its suspect appearance and condition on receipt, it was not considered representative by ORF and was, therefore, deleted from further consideration.

2.2 Laboratory Tests

The detailed descriptions of the test specimen formulations and the laboratory tests are given in Appendix I. Initially, a base metal tailing sample with the detailed mineralogy was sent to Dr. Davidovits for preliminary screening to determine the most suitable geopolymer for the project. The geopolymer selected, GP-50, is made up of two parts, GP-50A, a liquid, and GP-50B, a white mineral powder, specified to be added in equal parts. The approximate composition of the geopolymer is given in Table 1.

TABLE 1 **Composition of Geopolymer** *

	GP-50(A) (Hardener) (%)	GP-50(B) (Resin) (%)
SiO_2	20.95	33.71
Al_2O_3	-	16.68
Fe_2O_3/TiO_2	-	1.10
K_2O/Na_2O	25.98	0.79
CaO	-	33.65
MgO	-	3.01
F^-	-	12.22
H_2O	53.03	
Total	99.96	101.16

* Supplied by Dr. J. Davidovits

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Subsequently, various ratios of geopolymer/aggregate/tailings were examined. A formulation that poured, formed and set up well for all the tailing samples was desired. Based upon visual examination, the following tailings/sand/geopolymer ratio was established by ORF and Dr. Davidovits:

Tailings	32.5%
Sand	50.0%
GP-50A (hardener)	8.75%
GP-50B (resin)	8.75%

Two different bricks were made from each of the potash, base metal and uranium tailing samples; a 1400 ml block and a 222 ml tube. Only a 1400 ml block was made from the coal sample. The blocks were air cured for 14 days after which they were cut into three equal sections. One section was tested for leachate extraction, hydraulic conductivity, specific gravity and porosity. Another section was air cured for a further seven days after which it was subjected to the same tests. The remaining section has been retained for reference. The tubes were air cured for 14 days after which they were submitted for compression and cohesion tests.

All leachate extraction tests were performed by the Water Waste Management group at ORF. The analysis was performed in accordance with Regulation 309 of the Environmental Protection Act of Ontario, 1980. A description of the procedure is given in Appendix B of Appendix 1. Additionally, the uranium sample was analyzed for radium 226 emission by Eldorado Resources Limited.

The remaining tests noted were conducted by Golder Associates. The base metal, uranium and potash samples were tested for compression strength and cohesion. All of the tailings were tested for porosity, hydraulic conductivity, and specific gravity.

3.0 RESULTS AND DISCUSSION

3.1 Bonding

All tailing samples tested could be bound with aggregate and geopolymer and set in a reasonable amount of time (ie. less than 12 hours) at room temperature (20°C). It is anticipated that set time would be influenced by temperature to a certain degree. Colder temperatures would likely increase the set time, while warmer temperatures may decrease it. Set times may also be influenced by the proportions of aggregate, tailings and geopolymer used. It may be possible to minimize set times through a combination of temperature control and/or aggregate/tailings/geopolymer ratio in any specific tailings application.

No samples were prepared without the use of aggregate and, therefore, no conclusions can be reached on whether the geopolymer can bind tailings without the addition of aggregate.

3.2 Strength Tests

Base metal, uranium and potash tailing tube samples were each tested for compressive strength. These sample tubes showed compressive strength after curing for a minimum of 14 days. The results ranged from a high of 5242 kPa for a uranium tailings/geopolymer sample, to a low of 614 kPa for the potash/geopolymer sample. These results, including confining pressures for the triaxial tests, are detailed in Appendix D of Appendix I. The results are summarized in Table 2.

The cohesive strengths of these formulations was not determined. However, it is believed that the tailings/geopolymer formulations are essentially non-cohesive or have limited cohesive strength. This is

TABLE 2 **Triaxial Compression Test Results**

Tailing	14 Day Set Time Compression Stress kPa	Confining Pressure kPa
Base	2,724	172.2
Metal	2,142	344.5
	2,855	689.0
Uranium	3,313	172.2
	2,577	344.5
	5,242	689.0
Potash	1,502	172.2
	614	344.5
	1,160	689.0

All tests performed by Golder Associates

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based on the essentially granular nature of the materials and the results of the undrained compression tests. It is not known to what extent the changing of the formulations may improve the cohesive strength of the material for any specific tailings application.

No tests have been performed during this study to determine changes in structural properties or strength during extreme temperature changes (ie. freeze-thaw).

3.3 Hydraulic Conductivity Tests

Hydraulic conductivity testing was completed on all tailing formulations. Details of the testing and results are provided in Appendix D of Appendix I. The test results for hydraulic conductivity, specific gravity and porosity are summarized in Table 3. Hydraulic conductivities ranged from 10^{-4} cm/sec to 10^{-8} cm/sec, under various hydraulic gradients and varying sample porosities. The results indicate that the hydraulic conductivities are highly variable and are highly dependant on the tailings/aggregate properties and the tailings/aggregate/geopolymer formulation.

→ formulation was same for all samples.

basically it depends on everything

The hydraulic conductivity should be able to be minimized for any specific application but will always be a function of the properties of the components and their exact ratios in the formulation. Achieving uniformly low hydraulic conductivity for any specific application will also be dependant on quality control in formulation and on site application.

this does not say anything

Sample curing in water may lower the hydraulic conductivity of a specific geopolymer/tailings formulation; however, this was not tested for in this study.

again !

TABLE 3 **Summary of Physical Test Results**

Tailing	Set Time (Days)	Physical Test Results: Hydraulic Conductivity (cm/s)	Specific Gravity (g/cc)	Porosity (%)	
Base	14	1.14×10^{-5}	2.49	29.2	} ~ of sand
Metal	21	1.91×10^{-5}	-	29.4	
Coal	14	2.85x10-6	1.96	13.6	} less than gravel ~ sandstone, dolomite etc.
	21	1.95×10^{-6}	-	17.6	
Uranium	14	1.17×10^{-4}	-	23.5	like silty sand, silt, till
	21	3.53×10^{-5}	-	21.7	
Potash	14	5.15×10^{-8}	2.38	34.8	glacial till, ~~glacial deposit~~ marine clay
	21	6.21×10^{-8}	-	32.3	

All tests performed by Golder Associates

1×10^{-7} to 1×10^{-4} = similar to sandstone, dolomite, silty sand silt, glacial till

Porosity of sand generally

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3.4 Leachate Extraction

Leachate extraction tests were conducted on coal, potash, base metal and uranium tailings/geopolymer formulations. Leachate radium 226 results were completed for the uranium samples also. Detailed test results and procedures are included in Appendix B of Appendix I. Table 4 summarizes the leachate extraction results. The radium 226 results are presented in Table 5.

It is difficult to measure the effectiveness of the geopolymer formulations in stabilization of contaminants from the test results provided. No leachate extraction tests on the tailing samples themselves were completed for comparison. Based on a typical value reported by ORF for uranium tailings (not the sample tested), it would seem that the geopolymer formulation may be effective in stabilizing the radium 226 in the uranium tailings.

Actual leachate extraction data for the base metal tailings obtained from the Ontario Ministry of the Environment (MOE) in January 1986 are presented in Table 6. While these results do not represent the actual samples used in the current study, they should be fairly representative, so an initial comparison can be made.

The leachate extraction results for the base metal (Kam Kotia) tailings/geopolymer formulation seem to indicate the polymer formulation may be effective to varying degrees in stabilizing some base metals. Others are inconclusive. No other firm conclusions can be made on the coal or potash formulations.

TABLE 4 **Leachate Extraction Results**

	Coal		Base Metal		Uranium		Potash	
	14 days	21 days	14 days	21 days	14 days	21 days	14 days	21 days
Chloride	-	-	-	-	-	-	7500	7440
Barium	0.29	0.32	0.13	0.14	0.028	0.028	0.12	0.10
Boron	0.13	0.17	<0.02	0.07	0.06	0.11	<0.02	0.15
Cadmium	<0.002	<0.002	0.014	0.016	<0.002	<0.002	<0.002	<0.002
Chromium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Lead	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Cobalt	<0.01	<0.02	0.16	0.17	0.06	0.04	<0.01	<0.02
Zinc	<0.02	<0.02	3.1	4.4	<0.02	0.08	<0.02	<0.02
Bismuth	<0.2	<0.2	<0.2	<0.2	0.36	<0.2	<0.2	<0.2
Phosphorus	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Beryllium	<0.002	<0.005	<0.002	<0.005	<0.002	<0.005	<0.002	<0.005
Silicon	25	26	55	55	21	20	18	15
Iron	0.21	0.71	0.06	0.09	0.11	0.34	0.02	0.12
Manganese	1.2	1.4	1.1	1.6	1.7	1.5	0.77	0.75
Calcium	520	220	540	690	680	670	560	540
Magnesium	17	20	12	14	16	17	44	43
Copper	0.01	0.02	0.19	0.39	<0.01	0.02	<0.01	0.02
Aluminum	<0.01	0.02	<0.01	<0.02	<0.01	<0.02	<0.01	<0.02
Vanadium	0.06	0.05	<0.01	<0.01	0.07	0.05	0.03	0.01
Molybdenum	<0.05	0.02	0.06	<0.02	<0.05	0.03	0.09	0.05
Nickel	0.02	0.02	0.03	0.04	0.23	0.21	0.03	0.02
Sodium	16	13	20	23	12	111	3300	3100

All results in mg/L. All tests performed by ORF.

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TABLE 5 **Radium 226 Leachate Results From Uranium Tailings**

Tailing	Ra 226 (pCi/L)	
	14 day	21 day
Uranium	21.9 ± 2.5	18.7 ± 2.0

All tests performed by Eldorado Resources Limited

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TABLE 6 **Base Metal Leach Comparisons**

Base Metal	MOE Tailings Leach Results	ORF Tailings/Geopolymer Leach Results
Iron	110 - 660	0.06
Manganese	0.73 - 1.7	1.1
Aluminum	52 - 110	<0.01
Barium	0.015 - 0.46	0.13
Beryllium	<0.01	<0.002
Cadmium	0.03 - 0.27	0.014
Cobalt	0.48 - 1.7	0.16
Chromium	0.039 - 0.10	<0.01
Copper	11.0 - 43	0.19
Molybdenum	<0.01	0.06
Nickel	0.44 - 0.59	0.03
Lead	<0.03 - 0.04	<0.02
Vanadium	0.031 - 0.19	<0.1
Zinc	12 - 27	3.1

All concentrations in mg/L

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4.0 POTENTIAL USES OF GEOPOLYMERS FOR MINE TAILINGS

4.1 Solidification

Tailings tested in this study can be solidified using geopolymer and aggregate. The technique produced solidified tailings of varying compressive strength and hydraulic conductivity. The formulations set in a reasonable time period, and preparation of the geopolymer/aggregate/tailings mix should be adaptable to large scale production. The strength and hydraulic conductivity of any mix depend on the tailings used and the formulation of tailings/aggregate/geopolymer. It may be possible to vary specific tailings/geopolymer formulations to improve hydraulic conductivity and/or strengths. Therefore, full scale testing is required for any specific tailing to ensure that desired strength and hydraulic conductivity can be obtained for solidification using the geopolymer technique.

why the doubt?

No tests were conducted to determine if solidification will occur without the addition of aggregate. It is likely that, in most applications, some amount of aggregate will be required. Therefore, the availability and costs of aggregate, as well as the additional costs associated with the necessary increase in the containment area, will have a bearing on the decision to use this technique in any particular tailings management project.

essential test

right on

where is the documented advantage?

In most of these respects, the geopolymer technique is similar to other presently available tailing solidification techniques. The geopolymer, however, may be more durable than other methods. This has not been tested for or examined in this study. The effects of tailing materials and their constituents in the geopolymer matrix on the potential long term durability of the geopolymer should also be addressed in further studies.

nothing to prove this

4.2 Capping

The geopolymer technique could possibly be utilized to solidify the top layer of a tailings mass as a cap. Varying hydraulic conductivity or strength may be required as with complete solidification.

No shear strength tests have been conducted for the geopolymer technique in this study. However, due to the anticipated non-cohesive nature of the materials, it is not likely to be high. Capping applications are subjected to increased shearing and tensile stresses due to potential differential settlement of the underlying tailings mass. A cap technique may also be more vulnerable to changing temperature extremes and cracking due to its relative thinness when compared to a complete tailings mass stabilization.

Limited cracking due to temperature extremes or differential settlement could have possible serious negative effects for capping applications if they occurred. A major criteria for any capping technology is the prevention of the infiltration of water into the tailings mass and the conveyance of surface runoff. Cap cracking could seriously jeopardize this function. This function is much more critical for a capping application than a complete mass stabilization technique. Freeze-thaw tests were not conducted in this preliminary study.

If the geopolymer technique does have problems with cracking due to settlement and/or changing temperature extremes, this could possibly limit the use of the geopolymer technique in some applications for capping. Further bench scale testing is required for these parameters before any large scale tests or application of geopolymers as a cap could be undertaken.

4.3 Stabilization

The leachate extraction tests undertaken in this study make it difficult to determine the effectiveness of the geopolymer technique to achieve stabilization. No head assays or leachate extraction tests of the tailings themselves were undertaken for comparison purposes.

The results do indicate, however, that some stabilization can be achieved for various tailing constituents. It is impossible to determine if this stabilization is optimal as properties are likely affected by the tailings composition and the geopolymer/aggregate formulation.

Since the stabilization results may or may not be representative or optimal for the particular tailings tested, no meaningful comparison of stabilization properties can be made with currently available tailings stabilization techniques. Therefore, further bench scale tests should be completed before this technique is seriously considered for any specific tailings stabilization project.

5.0 CONCLUSIONS AND RECOMMENDATIONS

This preliminary study has indicated that the addition of geopolymer and aggregate to certain tailing samples will solidify those samples. Additionally, it has been determined that there is a potential for stabilization of various tailing samples; however, this has not been proven conclusively.

Extensive additional bench scale test work is required to further research the potential of geopolymer technology in mine tailing management applications. Further research that is required includes:

1. **Determining the requirement for sand aggregate.** It must be established if aggregate is required and if not, the changes in physical properties when aggregate is not added. If it is determined that aggregate is necessary, then the grade of aggregate and the amount of aggregate required for optimum characteristics must be determined.

2. **Optimization of geopolymer.** The various types of geopolymer must be examined to determine what is optimum for each type of tailing. Additionally, the amount of geopolymer added must be optimized.

3. **A study on the effects of freeze-thaw.** The climate in Canada is such that extreme temperature fluctuations occur throughout the year. The effects of freeze-thaw and the cyclic nature of this phenomena on the geopolymerized tailings must be investigated.

4. **A detailed study of the potential for stabilization of tailing masses.** This study has indicated that the potential exists for immobilizing hazardous or toxic elements

within the geopolymerized tailings. However, this was not proven conclusively. A more detailed leaching study should be conducted on various tailing samples. All analysis should be conducted on the native tailings before geopolymer addition as well as on the geopolymerized samples. Additionally, the same tests should be conducted on tailing samples solidified using other technologies such as cement solidification.

5. **A detailed economic study.** An economic study examining the costs of geopolymer applicaton should be conducted by an independant, third party consultant. The cost implications to the overall tailings system (ie. size of tailings containment area, mixing process etc.), in addition to the cost of the geopolymer and any aggregate that may be required, must be researched in detail.

6. **A technology comparison.** A detailed study comparing geopolymer technology to other tailings management technologies should be conducted. All aspects of tailings management should be compared.

7. **Determining long term durability.** Long term durability should be examined, and the effects on durability of tailings in the geopolymer/aggregate matrix should be explored.

Geopolymers show potential for application in mine tailings management; however, it is recommended that further extensive additional bench scale laboratory test work and office studies be conducted prior to the use of geopolymers in any field tests or actual mine tailings management schemes.

All of which is respectfully submitted.

COMCOR WASTE MANAGEMENT CONSULTANTS
A Division of Comcor Waste Systems Ltd.

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APPENDIX I

Preliminary Evaluation Of Geopolymers As An Additive For Mine Tailing Utilization

Materials Division

PRELIMINARY EVALUATION OF GEOPOLYMERS AS AN ADDITIVE FOR MINE TAILING STABILIZATION

FINAL REPORT

for

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July 30, 1987

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Specific Gravity, Porosity, Permeability
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1. INTRODUCTION

The mining industry, in general, has a problem with the disposal of tailings that is environmentally acceptable. Hazardous elements present in tailings must be chemically stabilized and not be leached out into the environment through ground water seepage, surface water run-off, or by airborn dust. For example, acid generation in coal and base metal tailings due to oxidation of pyrite and other sulphide minerals; chloride and radium needs be controlled in potash and uranium tailings respectively.

Canmet and the Ontario Research Foundation have recently been interested, in looking at alternative methods to store tailings in an environmentally safe manner and at a reasonable cost. Ontario Research Foundation, under a contract from Canmet (1981-1985), investigated the disposal of Mid-west uranium tailings by the thin layered tailings deposition technique under simulated Northern Saskatchewan climatic conditions (1). In another contract from Canmet (1981), Ontario Research Foundation evaluated the stabilization of Elliott Lake type of uranium tailings. Additives that were tested include cement-based, lime-based, thermoplastic, organic polymer and an encapsulation method (2). These methods were looked at from the point of view of permanent disposal effectiveness, cost and availability of additives and processing equipment. It was concluded that none of the methods investigated, satisfied all of the stated requirements.

Canmet and Ontario Research Foundation have since continuously sought alternative methods for the permanent disposal of mine tailings. One possible new method is the application of geopolymer as an additive to tailings. Literature on geopolymer research has suggested that older mortars dating as far back as 7000 B.C., to the time of the Romans involved a geopolymeric setting (2, 3).

Archeological surveys have demonstrated the exceptional durabilibty of geopolymer or zeolitic cements. Research has also been done on hydroxylated zeolitic phases for encapsulating nuclear waste for repository conditions (2).

According to Dr. J. Davidovits of Barry University, Florida, geopolymers designed for industrial applications can reach compressive strengths of 10,000 - 20,000 kPa (4) and have potential to dispose mine tailings having long durability.

During 1986, meetings were held between Canmet and Ontario Research Foundation with Dr. J. Davidovits of Barry University, Florida, to evaluate the potential of geopolymers for mine tailing stabilization and hence, the disposal.

Further meetings with Canmet, Ontario Research Foundation, and a Canadian waste management company with demonstrated geotechnical experience (Comcor Waste Management Consultants), resulted in the award of a contract to conduct preliminary evaluation on the application of geopolymers for mine tailing disposal.

The team formed to conduct scoping tests on several mine tailings (coal, uranium, base metal and potash) using geopolymers under the contract from DSS (Canmet, G.M. Ritcey), included Comcor Waste Management Consultants as primary contractor providing geotechnical input to the project; while Ontario Research Foundation, based upon their tailing management experience acting as a subcontractor, provided the bench scale test work. Dr. J. Davidovits (Barry University, Florida) provided expertise in the geopolymer technology field to Ontario Research Foundation.

This report describes the test work that was undertaken at Ontario Research Foundation on the first phase of the project.

2. DESCRIPTION OF GEOPOLYMER TECHNOLOGY

Briefly, geopolymers are semi-amorphous, three dimensional networks of poly silicon-oxo-aluminates: or abbreviated to poly-sialates. The poly-sialate network consists of SiO_4 and AlO_4 tetrahedra linked alternatively by sharing all the oxygens. Positive ions such as Na^+, K^+, Ca^{++}, Ba^{++}, NH_4^+ and H_3O^+ must be present to neutralize the frame work. Poly-sialates have the following empirical formula (5):

$$M_n(-(SiO_2)_z - AlO_2)_n \cdot WH_2O$$

Where:

M is a monovalent cation such as K^+, Na^+
n is the degree of polycondensation
z is 1, 2, or 3
W is the amount of water present

Three types of polysialates have been distinguished (3):

poly (sialate) (PS)

$$-\,Si\,-\,O\,-\,\overset{(-)}{Al}\,-\,O\,-$$
$$\quad\;\; O \qquad\quad O$$

poly (sialate-siloxo) (PSS)

$$-\,Si\,-\,O\,-\,\overset{(-)}{Al}\,-\,O\,-\,Si\,-\,O\,-$$
$$\quad\;\; O \qquad\quad O \qquad\quad O$$

poly (sialate-disiloxo) (PSDS)

$$-\,Si\,-\,O\,-\,\overset{(-)}{Al}\,-\,O\,-\,Si\,-\,O\,-\,Si\,-\,O\,-$$
$$\quad\;\; O \qquad\quad O \qquad\quad O \qquad\quad O$$

Applications have been developed which use sodium-poly(sialate), (Na)-PS; potassium-poly(sialate), (K)-PS; (sodium, potassium) -poly(sialate-siloxo), (Na, K)-PSS; and potassium-poly(sialate-silox), K-PSS geopolymeric materials. Geopolymers are similar to organic resins which polycondense at a low temperature, within a short period of time (hours). The polycondensation process forms the three dimensional framework. The framework may be in the form of chain or ring polymers.

The polycondensation process is generally conducted by reacting a soluble silicate (sodium silicate or potassium silicate) with a reactive sialate such as calcined kaolin. Other mineral powders may be added to the reactive sialate to control set time, processability and chemical composition of the final product. Examples of mineral additives include Flourite (CaF_2), silica (SiO_2) and lime (CaO).

Similar to other cements, geopolymers also require an aggregate to form a hard final product. A graded sand for the cement industry works well with geopolymer cements. The mine tailings will replace the aggregate required to form solidified material. Some aggregate (available at the mine site) may be required to maintain a chemical balance.

3. TEST PROCEDURE

3.1 Selection of Tailing Samples

A total of four (4) mine tailing samples were selected for the project. These samples, in consultation with scientific authority (G.M. Ritcey) were selected in order to provide a cross section of Canadian mine tailings. The following samples were selected:

* Base metal (KamKotia, Ontario)
* Potash (PCS, Saskatchewan)
* Coal (Hinton Mines, Alberta)
* Uranium (Mid-west, Saskatchewan)

A fifth tailing sample (Key Lake Uranium tailing) was also initially selected for the study. The sample, however, did not appear to be representative since it was received in a dry and ground state. Consequently, it was jointly decided to delete this sample from the screening program. All test data is however reported in the appropriate Appendices.

3.2 Selection of Geopolymer Formulation

A sample of the base metal tailings together with mineralogy was sent to Barry University for preliminary screening and subsequent selection of a suitable geopolymer for the project. The base metal tailings (KamKotia) were intitially formulated with a geopolymer designated as GP-25. A sand aggregate was incorporated with the geopolymer and tailings. Based upon these initial tests, Dr. Davidovits selected geopolymer GP-50 for further evaluation at Ontario Research. The selected geopolymer formulation consisted of two parts, GP-50(A) and GP-50(B), which were specified to be added in equal weight proportions. GP-50(A), the hardener, was liquid based while GP-50(B) consisted of a fine white mineral powder. The chemical analysis of the two parts is shown in Table 1.

The selected geopolymer/tailing formulation included filler material such as sand aggregate to remove excess water. However, a sand aggregate may be expensive to use. In a mining situation, locally available silicious and other sand materials can be considered to supplement the optimum filler requirement in addition to the chosen tailing.

3.3 Preliminary Scoping Tests

With consultation and direction from Dr. J. Davidovits, Ontario Research Foundation screened a number of geopolymer/aggregate/tailing ratios. Potash and coal tailings were used in the screening process. The formulations used in the screening process are summarized in Table 2. Equal weights of resin and hardener were used in all the samples prepared at Ontario Research Foundation. The total weight of geopolymer used is shown in Table 2. Each test specimen was examined visually for similarity to concrete consistency, and whether it set in a reasonable amount of time (overnight). The mixing procedure used was as follows:

* mix tailing and sand
* add hardener to resin in a dropwise manner and stir
* mix geopolymer to sand/tailing
* add water, if required, until a concrete consistency has formed
* add mixture to moulds and vibrate to remove entrained air
* allow to set overnight and de-mould
* visual examination for strength

Shown in Appendix A are photographs which visually describe the steps required to prepare the geopolymer/tailing specimens. Based upon a visual examination of the hardened products, the following formulation was agreed upon:

Tailing	32.5%
Sand	50%
Resin (GP-50A)	8.75%
Hardener (GP50B)	8.75%

The sand ratio remained similar to the ratio used in the preliminary scoping tests while the tailing content was increased with respect to the geopolymer and sand aggregate. It was believed that this would improve the economic viability of using a geopolymer for mine tailing stabilization.

The above formulation was used for all subsequent test specimens. This formulation was chosen because it would give good a consistency (pourability and forming characteristics) for all of the tailing samples.

3.4 Preparation of Test Specimens

Based upon the preliminary scoping tests, two geometrically different shapes were chosen for the subsequent test work. The first test specimen shape was a block having an approximate volume of 1400 ml. After setting for fourteen days, each block was cut with a diamond saw into three sections . One of the portions was analyzed for leachate, permeability, specific gravity and porosity tests. After another seven days of setting, the second portion was analyzed for leachate, permeability and porosity tests. The remaining portion has been retained for reference or for freeze-thaw evaluation.

The second specimen shape was moulded into tubes having an approximate volume of 222 ml. Three tubes were prepared for each tailing sample. After fourteen days of setting time, the samples were analyzed for compression, cohesion and shear strengths.

Typical tailing samples such as KamKotia Mid-west and potash were prepared with the second specimen shape. KamKotia tailings contain much more sulphides than coal tailings (86% sulphide compared to 10% sulphide for coal) consequently, acid generated from KamKotia will be more than coal. All four tailing samples were prepared with the first specimen shape. Due to the availability of tailing, the weight of prepared test specimens varied from sample to sample. The formula ratio described in section 2.3 was however adhered to. The weight of each geopolymer/tailing composite prepared is summarized in Table 3. The total weight of geopolymer is also shown in Table 3. Equal weight preparations of the hardener and resin were used in all cases.

3.5 Chemical and Physical Testing

A leachate extraction analysis was performed on all five tail/geopolymer test samples, including the sample prepared by Dr. J. Davidovits of Barry University. The analysis was performed in accordance with the Revised Environment Regulation 309 of Ontario, 1980. A brief description of the procedure is presented in Appendix B. All samples were broken up to pass a 9.5 mm sieve prior to commencing the extraction process.

Appendix B describes the leachate extraction procedure undertaken by the water waste management group at Ontario Research. The leachate analysis was performed on samples that have been air cured at fourteen and twenty-one days in order to investigate if any change will take place with time.

The uranium tailing sample was analyzed for radium 226 emissions. The analysis was performed after fourteen and twenty-one day curing times. The analyses were performed by Eldorado Resources Limited (Appendix C).

The following tests were performed by Golder Associates, Mississauga. KamKotia base metal, Mid-west uranium and potash tailings were evaluated for triaxial cohesion, shear strength and compression. The above mentioned tailings plus the coal tailings were evaluated for porosity, permeability and specific gravity. Appendix D describes the test procedures undertaken by Golder Associates for each test.

Initially, it was proposed to conduct bulk density, water content and again size analysis on the tailing samples. At that time only three tailing samples were considered for the scoping tests. It was however later decided by the scientific authority to include a fourth tailing sample (Potash) in the scoping test work. In order to accommodate this change, it was agreed to delete bulk density, water content and grain size analysis from the scoping program.

4. RESULTS AND DISCUSSION

4.1 Leachate Extraction

The tests carried out were of a scoping nature. Therefore, the formulation has not been optimized for any of the tailing samples. Hence, one standard procedure was used.The leachate extraction results are summarized in Table 4. The elements shown in Table 4 are the elements that are considered hazardous by the Ontario Ministry of Environment. Also shown in Table 4 are the maximum allowable leachate criteria as specified by Schedule 4 criteria of the Ontario Ministry of Environment.

Excepting the initial KamKotia (base metal) tailings (GP-25), all tailing samples were analyzed for a total of twenty-two elements. These results are detailed in Appendix B. Also included in Appendix B for reference, are some other water quality criteria/guidelines of various regulatory bodies in Canada.

According to Schedule 4 of Regulation 309, all tailing samples were found to be neither leachate toxic, nor sensitive with respect to barium, boron, chromium and lead. In one case (KamKotia) the tails were found to exceed the criteria for cadmium, but are not considered to be leachate sensitive. Consequently, any hazardous elements present in any of the samples appears to be "locked" into the geopolymer/tailing matrix. This is encouraging since one of the desired properties of the final geopolymer/tailing composite is to resist leaching and be permanently disposed (see Section 1 of this report).

The sodium and chloride results for the potash sample are reasonably low. Typical potassium tailings contain 220,000 mg/L of dissolved chloride while the geopolymer tailings leachate contained up to 7,500 mg/L resulting in up to 89% decrease in chloride contents.

In all cases, the leachate results remained fairly constant between the fourteen and twenty-one day tests. This also includes the sodium and chloride concentrations in the leachate filtrate.

4.2 Radium 226 Analysis

Shown in Table 5 is the fourteen and twenty-one day radium 226 analysis; the results are low. The results remained reasonably constant between the fourteen and twenty-one day tests.

Results obtained with Mid-west compares with the limit of 28.4 pCi/L (total) suggested by the International Atomic Energy Agency. These results also compare well with results reported in the literature (1). In fact, the results are in the range of values reported by using the microencapsulation methods of treating uranium tailings (1).

4.3 Physical Test Results

The physical test results are summarized in Tables 6 and 7. Details of the data are presented in Appendix D. The setting of geopolymers appear not to be the same as a typical cement. Consequently both shear strength and cohesion could not be calculated from the test data. Further test work will be required to resolve this.

It should be pointed out that the physical properties of a cement or concrete is highly dependent upon the type of aggregate chosen, as well as the type of cement applied. The aggregate is generally graded (control of particle size distribution) in order to obtain a targeted binder (cement) to aggregate ratio. The strength of the aggregate will also affect the strength of the final concrete.

In the present project, optimum aggregate sand gradation and aggregate: binder (geopolymer) to tailings ratio have not been attempted. This must be performed separately for each tailing.

As mentioned earlier (see Section 1), the objective of the present program was to determine if any strength can be developed with a geopolymer/tailing mixture.

The data shown in Table 6 indicates that all of the geopolymer composites have hydraulic conductivity in the range of 10^{-5} to 10^{-8} cm/sec. Typical low permeable materials have hydraulic conductivity in the range of 10^{-8} cm/sec. This variation may be, in part, by the selection of sand aggregate used; as well as the ratio of geopolymer/tailings/sand used in the formulation. Excepting the Mid-west tailings, the permeability remained fairly constant between the fourteen days and twenty-one days set time. The permeability of Mid-west tailings increased by one order of magnitude from fourteen to twenty-one days of setting. The results indicate that the sand chosen for GP-50 test (KK-1) probably did not have an optimum particle size gradation.

French Patent 2, 528, 818, June 22, 1986 issued to J. Davidovits and C. Bautte, states that the hydraulic conductivity of a geopolymer cement improves (decreasing cm/s) when the cement is cured in water. Therefore, in a real situation whether used as a cap, back fill, or complete stabilization of the tailing, an option for curing the geopolymer in water (i.e. sprays) can be considered as an option to improve hydraulic conductivity performance.

Excepting the coal tailing composite, all the porosity data remained fairly constant from fourteen to twenty-one days of setting; the coal tail increased slightly from fourteen to twenty-one days of setting.

The specific gravity of the various geopolymer/tailing composites were fairly close to each other. This may be explained by the fact that the specific gravity is affected by the specific gravity of the sand aggregate. The one notable exception was the coal tailings, which had a low specific gravity. In this case, the relatively low specific gravity of coal will tend to reduce the specific gravity of the composite.

The triaxial compression test results are summarized in Table 7. The compressive strength results (614 kPa to 5,242 kPa) indicate that all of the geopolymer/tails composites have bonding strength.

5. CONCLUSIONS

Overall, geopolymer as an additive to stabilizing mine tailings shows promise. It appears that the method must be optimized for each tailing type (coal, potash, etc.) as well as for each mine.

Parameters that must be optimized include the following:

* sand aggregate requirements, if any
* grade of sand aggregate
* amount of sand aggregate addition
* amount of geopolymer addition
* type of geopolymer formulation

The preferred method of stabilizing the mine tailing must also be taken into account. Possible methods include stabilizing the entire tailings or stabilize the top of a tailing pile. This will affect the cost of stabilizing tailings with geopolymer additives.

In general, hazardous elements present in mine tailings can be potentially immobilized by the geopolymer additive. Additionally, the resultant geopolymer/tailing composite does form a solid mass having bonding strength. Bonding strength potentially can be improved by optimizing the parameters discussed above.

In conclusion, the results show potential for application in mine tailing management. Further test work should be conducted on geopolymer additives for mine tailing stabilization.

Craig A Booth

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3. Davidovits J. and Vial D., "Antique Mortar and Antique Man-Made Stone Artefacts", presented at the American Chemical Society National Meeting, Denver, April 9, 1987.

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Table 1

Composition of Geopolymer *

	GP-50(A) (Hardener) (%)	GP-50(B) (Resin) (%)
SiO_2	20.95	33.71
Al_2O_3	-	16.68
Fe_2O_3/TiO_2	-	1.10
K_2O/Na_2O	25.98	0.79
CaO	-	33.65
MgO	-	3.01
F^-	-	12.22
H_2O	53.03	-
Total	99.96	101.16

* Supplied by Dr. J. Davidovits

Table 2

Preliminary Screening Formulations

Designation	Tailing Type	Formulation (g) Tail	Sand	GP-50(50/50)	H_2O
P-1	Potash	200	200	400	-
	Coal	200			
P-2	Potash	300	100	300	-
	Coal	300			
P-3	Potash	150	-	200	-
	Coal	150			
C-1	Coal	300	500	200	-
GP-25*	Base Metal	25%	50%	25%	-

* Prepared by Dr. J. Davidovits of Barry University, Florida.
The rest were prepared by Ontario Research Foundation.

Table 3
Test Specimen Formulations

Designation	Tail Type	Specimen Type	Formulation (g) Tail	Sand	GP50	H_2O
C-2	Coal	Block	275	423	148	-
P-4	Potash	Block	1054	1622	568	50
P-5	"	Tube	144	222	78	
KK-1	Base Metal	Block	1054	1622	568	-
KK-2	Base Metal	Tube	144	222	78	-
MW-1	Uranium	Block	1054	1622	568	-
MW-2	"	Tube	144	222	78	-

TABLE 4

PRELIMINARY LEACHATE RESULTS

SAMPLE	CURE (DAY)	ELEMENTS (mg/L) B	Cd	Cr	Pb	Ba	Na	Cl	Ra**
CRITERIA (MAX.)*	-	5.0	0.005	0.05	0.05	1.0	-	-	-
COAL	14	0.13	<0.002	<0.01	<0.02	0.29	16	-	-
	21	0.17	<0.002	<0.01	<0.02	0.32	13	-	-
POTASH	14	<0.02	<0.002	<0.01	<0.02	0.12	3300	7500	-
	21	0.15	<0.002	<0.01	<0.02	0.10	3100	7440	-
BASE METAL									
	14	0.02	0.014	0.01	0.02	0.13	20	-	-
	21	0.07	0.016	0.01	0.02	0.14	23	-	-
URANIUM	Head***	-	-	-	-	-	0.16%	-	3841
	14	0.06	0.002	0.01	0.02	0.03	12	-	21.9
	21	0.11	0.002	0.01	0.02	0.028	111	-	18.7

NOTES:

* As per Schedule 4 of Ontario Environmental Protection Act.
- If leachate levels exceed these criteria by more than one hundred times, the waste is leachate toxic.
- If leachate levels exceed these criteria by between ten and one hundred times, the waste is leachate sensitive.

** Measured as Radium 226 pCi/L, except for Head which is measured as Ra 226 pCi/L.

*** Average values reported in DSS File No. 15 SQ 23440-3-9004

TABLE 5

RADIUM 226 LEACHATE RESULTS FROM
URANIUM TAILINGS

Tailing	Ra 226 (pCi/L)	
	14 day	21 day
MW	21.9 ± 2.5	18.7 ± 2.0

ORF

Table 6

Summary of Physical Test Results

Identification	Tail	Set Time (Day)	Physical Test Results		
			Hydraulic Conductivity (cm/s)	Specific Gravity (g/cc)	Porosity (%)
GP-25	Base Metal	-	3.15×10^{-8}	2.30	42.2
KK-1	Base metal	14	1.14×10^{-5}	2.49	29.2
		21	1.91×10^{-5}	-	29.4
C-2	Coal	14	2.85×10^{-6}	1.96	13.6
		21	1.95×10^{-6}	-	17.6
MW-2	Uranium	14	1.17×10^{-4}	-	23.5
		21	3.53×10^{-5}	-	21.7
P-5	Potash	14	5.15×10^{-8}	2.38	34.8
		21	6.21×10^{-8}	-	32.3

Table 7

Summary of Triaxial Compression Test Results

Identification	Tailing Type	14 Day Set Time Compression Stress kPa	Confining Pressure kPa
KK-1	Base	2,274	172.2
	Metal	2,142	344.5
		2,855	689.0
MW-2	Uranium	3,313	172.2
		2,577	344.5
		5,242	689.0
P-5	Potash	1,502	172.2
		614	344.5
		1,160	689.0

APPENDIX A

Photographs of the Steps Used to Prepare Geopolymer/Tailing Test Specimens

Fig. A1: Potassium Silicate Solution (Geopolymer Hardener)

Fig. A2: Dropwise Addition of Hardener to Resin

Fig. A3: Mixed Geopolymer

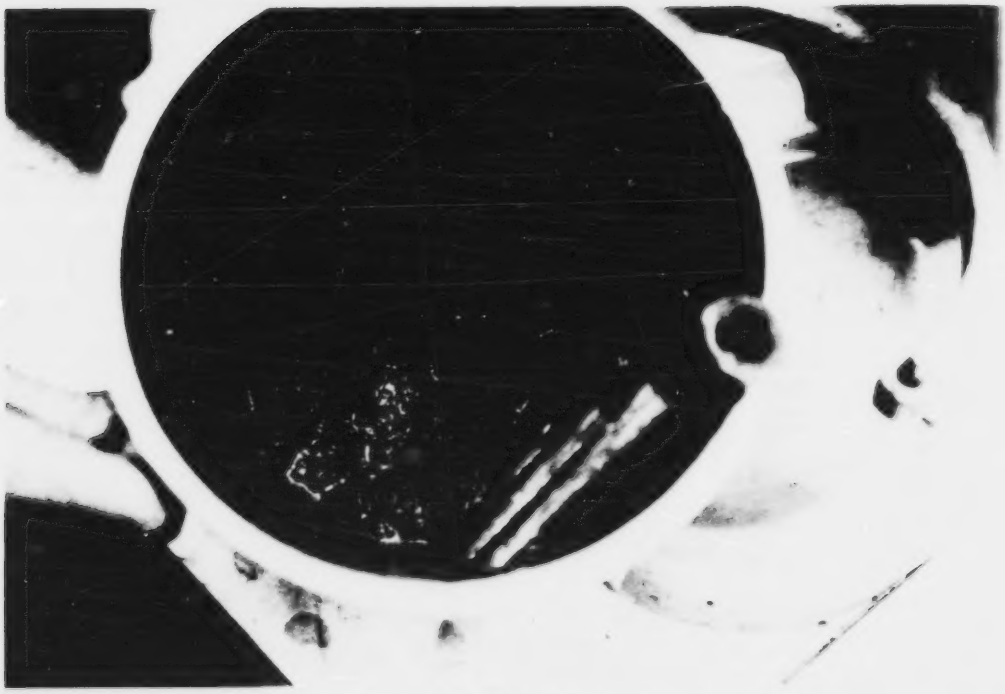

Fig. A4: Mixing of Geopolymer/Tailing/Sand (KamKotia Tails)

Fig. A5: Filling Mold with Geopolymer/Tailing/Sand Mixture

Fig. A6: Vibrating of Mixture to Remove Entrained Air

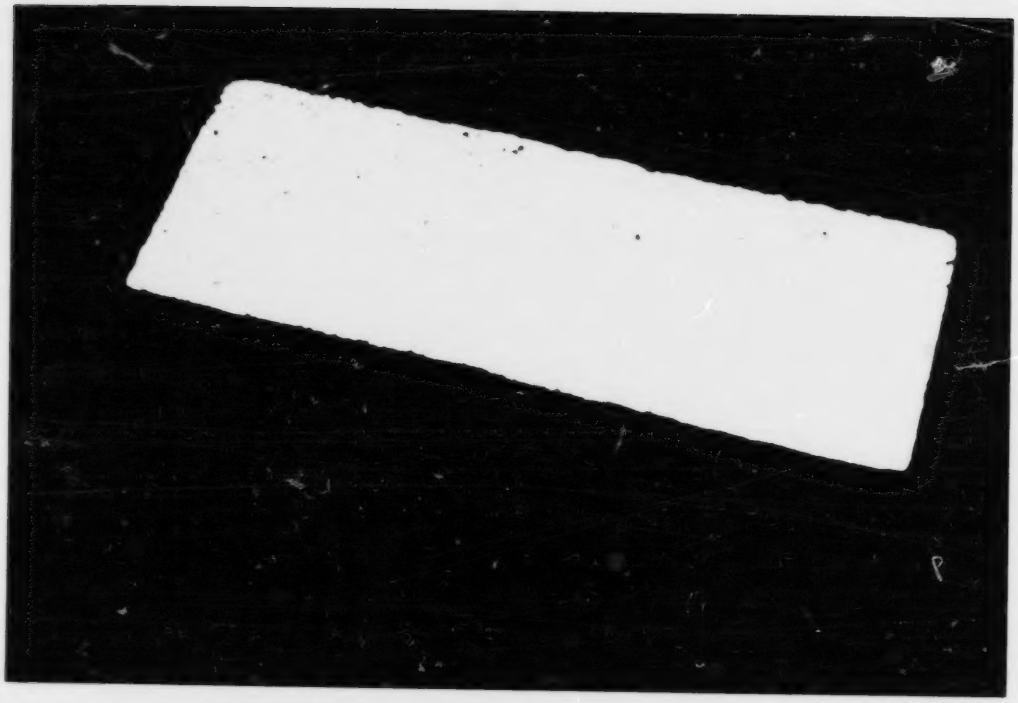

Fig. A7: Final Product (KamKotia)

Fig. A8: Final Product (Coal)

C

APPENDIX B

Leachate Test Results

April 16th, 1987

TO: C. BOOTH

Report No.: 87-48-40008-147

Identification: Work Order No. 30963

Specifications of Order: Perform Regulation 309 leachate extraction procedure on one waste sample (Comcor)

REFERENCE: Regulation 309, Revised Regulations of Ontario, 1980, as amended to O.Reg. 464/85, under the Environmental Protection Act, November, 1985.

LEACHATE EXTRACTION PROCEDURE

A 50 g aliquot of pre-ground sample was placed in a 1000 mL polypropylene bottle and 800 mL of deionized water added. After fifteen minutes extraction on a rotary tumbler (14 rpm), the solution pH was measured and quantities of 0.5 N acetic acid added to bring the pH to 5 ± 0.2.

The rotary extraction was continued with adjustments to pH 5 ± 0.2 as necessary, at intervals of one, three, six and twenty-two hours.

At the end of twenty-four hours of extraction, the total volume of liquid added was made to 1000 mL with deionized water and the final pH recorded.

The extract was filtered through 0.45 µm membrane. The leachate (filtrate) was analysed for trace metals by DC plasma emission spectrophotometry.

RESULTS

The results are listed in the attached table.

RESULTS OF REGULATION 309 LEACHATE EXTRACTION PROCEDURE

Client I.D.	GP Sample 9/4/87	
ORF I.D.	LEP 87-35	
Sample aliquot, g	50.00	
Deionized water, mL	985	
0.5 N acetic acid, mL	15	
Initial, 15 min. pH	9.49	
Final, 24 hr. pH	5.42	
	mg/L	Schedule 4 Criteria* mg/L
Boron	0.07	5.0
Cadmium	< 0.002	0.005
Chromium	< 0.01	0.05
Lead	< 0.02	0.05

* If leachate levels exceed these criteria by more than one hundred times, the waste is leachate toxic. If leachate levels exceed these criteria by between ten and one hundred times, the waste is leachate sensitive.

SUMMARY

The "GP Sample 9/4/87" are neither leachate toxic nor sensitive with respect to boron, cadmium, chromium and lead.

Jane Lindsay

J.A. Lindsay
Water and Wastewater Assessment
Environmental & Chemical Engineering Division

JAL/jmm

May 27th, 1987

TO: C. Booth

Report No.: 87-48-40008-211
Identification: Work Order No. 30956
Specifications of Order: Perform Regulation 309 leachate extraction procedure on ten waste samples

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REFERENCE: Regulation 309, Revised Regulations of Ontario, 1980, as amended to O.Reg. 464/85, under the Environmental Protection Act, November, 1985.

LEACHATE EXTRACTION PROCEDURE

A 50 g aliquot of pre-ground sample was placed in a 1000 mL polypropylene bottle and 800 mL of deionized water added. After fifteen minutes extraction on a rotary tumbler (14 rpm), the solution pH was measured and quantities of 0.5 N acetic acid added to bring the pH to 5 ± 0.2.

The rotary extraction was continued with adjustments to pH 5 ± 0.2 as necessary, at intervals of one, three, six and twenty-two hours.

At the end of twenty-four hours of extraction, the total volume of liquid added was made to 1000 mL with deionized water and the final pH recorded.

The extract was filtered throught a 0.45 µm membrane. The leachate (filtrate) was analysed for trace metals by DC plasma emission spectrophotometry. The leachate, if requested, was analysed for chloride using ion chromatography.

RESULTS

The results of the leachate extraction procedures are found in Tables 1 and 2.

SUMMARY

According to Schedule 4 of Regulation 309 the ten waste samples are neither leachate toxic nor sensitive with respect to barium, boron, cadmium, chromium and lead.

APPENDICIES

For your information, attached are some other water quality criteria/guidelines.

Appendix I contains the maximum allowable concentrations for non-hazardous leachates according to Alberta Regulation 49.85.

Appendix II contains the criteria for non-hazardous waste in Quebec.

Appendix III contains guidelines for "desirable" drinking water concentrations in Ontario. Most of these are for "asthetic" quality only and concentrations exceeding the guidelines would not constitute a health hazard.

Appendix IV and V are taken from Environment Canada's Water Quality Sourcebook, A Guide to Water Quality Parameters, 1979, Addendum, and are comprised of the most stringent national and international drinking water standards existing in 1979.

Jane Lindsay

J.A. Lindsay
Water and Wastewater Assessment
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JAL/jmm

TABLE 1: SUMMARY OF ONTARIO REGULATION 309 LEACHATE EXTRACTION PROCEDURES ON 14 DAY SAMPLES

Client I.D.	C-2 14 DAYS	KK-1 14 DAYS	KL-5 14 DAYS	MW-1 14 DAYS	P-5 14 DAYS	SCHEDULE 4 CRITERIA*
ORF I.D. (LEP)	87-40	87-41	87-42	87-43	87-44	
Sample aliquot, g	50.00	50.00	50.00	50.00	50.00	
Deionized water, mL	916	927	863	915	932	
0.5 N acetic acid, mL	84	73	137	85	68	
Initial (15 min.) pH	10.9	10.4	10.7	10.8	10.9	
Final (24 hr.) pH	5.9	6.0	5.8	6.0	6.2	
Chloride, mg/L	-	-	-	-	7500	-
Barium, mg/L	0.29	0.13	0.27	0.028	0.12	1.0
Boron, mg/L	0.13	<0.02	0.26	0.06	<0.02	5.0
Cadmium, mg/L	<0.002	0.014	<0.002	<0.002	<0.002	0.005
Chromium, mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	0.05
Lead, mg/L	<0.02	<0.02	<0.02	<0.02	<0.02	0.05
Cobalt, mg/L	<0.01	0.16	0.23	0.06	<0.01	-
Zinc, mg/L	<0.02	3.1	<0.02	<0.02	<0.02	-
Bismuth, mg/L	<0.2	<0.2	<0.2	0.36	<0.2	-
Phosphorus, mg/L	<0.5	<0.5	<0.5	<0.5	<0.5	-
Beryllium, mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	-
Silicon, mg/L	25	55	30	21	18	-
Iron, mg/L	0.21	0.06	<0.02	0.11	0.02	-
Manganese, mg/L	1.2	1.1	2.6	1.7	0.77	-
Calcium, mg/L	520	540	1300	680	560	-
Magnesium, mg/L	17	12	37	16	44	-
Copper, mg/L	0.01	0.19	0.01	<0.01	<0.01	-
Aluminum, mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	-
Vanadium, mg/L	0.06	<0.01	0.09	0.07	0.03	-
Molybdenum, mg/L	<0.05	0.06	0.12	<0.05	0.09	-
Nickel, mg/L	0.02	0.03	13	0.23	0.03	-
Sodium, mg/L	16	20	26	12	3300	-

* If leachate levels exceed these criteria by more than one hundred times, the waste is leachate toxic. If leachate levels exceed these criteria by between ten and one hundred times, the waste is leachate sensitive.

TABLE 2: SUMMARY OF ONTARIO REGULATION 309 LEACHATE EXTRACTION PROCEDURES ON 21 DAY SAMPLES

Client I.D.	C-2	KK-1	KL-5	MW-1	P-5	
	21 DAY	21 DAY	21 DAY	21 DAY	21 DAY	
ORF I.D. (LEP)	87-47	87-48	87-49	87-50	87-51	
Sample aliquot, g	50.00	50.00	50.00	50.00	50.00	
Deionized water, mL	912	912	848	906	933	
0.5 N acetic acid, mL	88	88	152	94	67	
Initial (15 min.) pH	10.9	10.4	10.7	10.8	10.9	
Final (24 hr.) pH	5.9	6.0	5.8	6.0	6.2	
						SCHEDULE 4 CRITERIA*
Chloride, mg/L	-	-	-	-	7440	-
Barium, mg/L	0.32	0.14	0.26	0.028	0.10	1.0
Boron, mg/L	0.17	0.07	0.33	0.11	0.15	5.0
Cadmium, mg/L	<0.002	0.016	0.004	<0.002	<0.002	0.005
Chromium, mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	0.05
Lead, mg/L	<0.02	<0.02	<0.02	<0.02	<0.02	0.05
Cobalt, mg/L	<0.02	0.17	0.21	0.04	<0.02	-
Zinc, mg/L	<0.02	4.4	0.07	0.08	<0.02	-
Bismuth, mg/L	<0.2	<0.2	<0.2	<0.2	<0.2	-
Phosphorus, mg/L	<0.5	<0.5	<0.5	<0.5	<0.5	-
Beryllium, mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	-
Silicon, mg/L	26	55	31	20	15	-
Iron, mg/L	0.71	0.09	0.02	0.34	0.12	-
Manganese, mg/L	1.4	1.6	2.8	1.5	0.75	-
Calcium, mg/L	220	690	1400	670	540	-
Magnesium, mg/L	20	14	38	17	43	-
Copper, mg/L	0.02	0.39	0.03	0.02	0.02	-
Aluminum, mg/L	0.02	<0.02	<0.02	<0.02	<0.02	-
Vanadium, mg/L	0.05	<0.01	0.06	0.05	0.01	-
Molybdenum, mg/L	0.02	<0.02	0.07	0.03	0.05	-
Nickel, mg/L	0.02	0.04	12	0.21	0.02	-
Sodium, mg/L	13	23	23	111	3100	-

* If leachate levels exceed these criteria by more than one hundred times, the waste is leachate toxic. If leachate levels exceed these criteria by between ten and one hundred times, the waste is leachate sensitive.

APPENDIX I

Alberta Regulation 48/85 Criteria

TABLE 3

PERSISTENT AND BIOACCUMULATIVE SUBSTANCES AND THEIR CONCENTRATIONS RESPONSIBLE FOR CLASSIFYING A WASTE AS BEING HAZARDOUS

	Concentration (ppm)
Aldrin	0.14
Antimony and compounds	100
Arsenic and compounds	5
Barium and compounds (excluding Basite)	100
Beryllium and compounds	1
Cadmium and compounds	1
Chlordane	0.3
Chromium and Chromium (VI) compounds	5
Chromium and Chromium (III) compounds	25
Cobalt and compounds	80
Copper and compounds	15
DDT, DDE, DDD (TDE)	0.1
2, 4 - Dichlorphenonyacetic acid	10
Dieldrin	0.1
Dioxin (TCDD)	0.003
Endrin	0.02
Fluoride Salts	180
Heptachlor	0.3
Kepone	0.5
Lead and compounds (inorganic)	5
Lindane	0.4
Mercury and compounds	0.2
Mirex	0.5
Methoxychlor	10
Molybdenum and compounds	350
Nickel and compounds	20
Pentachlorophenol	1
Polybrominated biphenyls (PBBs)	5
Polychlorinated biphenyls (PCBs)	5
Polychlorinated terphenyls (PCTs)	5
Selenium and compounds	1
Silver and compounds	5
Thallium and compounds	5
Toxaphene	0.5
Trichlorcethylene	0.5
2, 4, 5 - Trichlorophenoxyacetic acid	1
Vanadium and compounds	24
Zinc and compounds	20

APPENDIX II

Quebec Regulation Q-2, r.12.1 Criteria

SCHEDULE III

TABLE OF MAXIMUM CONCENTRATIONS - LIQUID WASTE OR SOLID WASTE LEACHATE
(s. 1)

Contaminants	Standards	
	liquid waste mg/l**	solid waste leachate mg/l**
Class 1		
Total Arsenic	1.0	5.0
Total Cadmium	2.0	2.0
Total Chromium	5.0	5.0
Total Copper	5.0	10
Total Mercury	0.05	0.2
Total Nickel	5.0	10
Total Lead	2.0	5.0
Total Selenium	1.0	1.0
Total Zinc	10	10
Total Sulphides	5.0	—
Total Fluorides	8.0	150
Cyanides Oxidizable By Chlorination	2.0	—
Phenolic Compounds	1.0	2.0
Total Mineral Oil and Grease	30	30
Total Polychlorinated Biphenyls*	0.3	0.01
Total Halogenated Hydrocarbons**	1.0	1.0
Total Monocyclic Aromatic Hydrocarbons**	1.0	1.0
Class 2		
Total Polycyclic Aromatic Hydrocarbons	1.0	0.01
Total Chlorodibenzo p-dioxine***	2.5×10^{-5}	2.5×10^{-4}
Total Chlorodibenzo Furan***	2.5×10^{-5}	2.5×10^{-5}
Other Inorganic Contaminants	10	10
Other Organic Contaminants**	1.0	1.0
Total Metals (including only As, Cd, Cr, Cu, Hg, Ni, Pb, Zn)	10	10

* The contaminants listed above are sampled and analyzed according to the procedure prescribed in "Procedure d'evaluation des caractéristiques de déchets solides et de boues pompables", published by the ministère de l'Environnement du Québec in 1985.

** Milligram (mg) of contaminants per litre (l) of liquid waste of leachate.

*** The standards for each category of contaminants shall be the sum total of all quantifiable values in excess of 0.01 mg/l, except for solid waste leachate of PCBs and PAHs for which the quantifiable value shall be 10 % of the standard for the total.

**** Residues contaminated by these compounds shall be contamined waste for which the maximum acceptable load is nil. The standard for each family of dioxins and furans, i.e., tetra, penta, hexa, hepta, and octo chloro compounds, shall be 1 500 picograms/litre.

Note: Compounds listed in Class 2 shall apply from the date fixed by proclamation of the Government.

SCHEDULE IV

TOXICITY CRITERIA
(s. 1)

In Tables I and II of this Schedule:

"Contaminant"* means a compound or an element contained in liquid waste or in solid waste leachate at a concentration greater than the following standards:

Compounds or elements	Standards	
	liquid waste mg/l**	solid waste leachate mg/l**
Total Arsenic	0.5	2.5
Total Cadmium	1.0	1.0
Total Chromium	2.5	2.5
Total Copper	2.5	5.0
Total Mercury	0.03	0.1
Total Nickel	2.5	5.0
Total Lead	1.0	2.5
Total Selenium	0.5	0.5
Total Zinc	5.0	5.0
Total Metals (including only As, Cd, Cr, Cu, Hg, Ni, Pb, Zn)	5.0	5.0
Total Sulphides	2.5	—
Total Fluorides	4.0	75
Cyanides Oxidizable By Chlorination	1.0	—
Phenolic Compounds	1.0	2.0
Polychlorinated Biphenyls	0.15	0.005
Halogenated Hydrocarbons	0.5	0.5
Monocyclic Aromatic Hydrocarbons	0.5	0.5
Polycyclic Aromatic Hydrocarbons	0.5	0.005
Chlorodibenzo-p-dioxin	1.5×10^{-4}	1.5×10^{-3}
Chlorodibenzo Furan	1.5×10^{-5}	1.5×10^{-5}
Other Inorganic Contaminants	5.0	5.0
Other Organic Contaminants	0.5	0.5

APPENDIX III

Ontario MOE Drinking Water Criteria
for Aesthetic Quality

Maximum Desirable Concentration (MDC)

This term is used for limits on substances which, when present at concentrations above the limits, are either aesthetically objectionable to an appreciable number of consumers or may interfere with good water quality control practices. These limits should not be exceeded whenever a more suitable supply or treatment process is, or can be made available at a reasonable cost.

The chemical substances shown in Table 2 should not be present in a water supply in excess of the concentrations indicated where, in the judgement of the Ministry, other more suitable supplies are, or can be made available.

TABLE 2
Maximum Desirable Concentrations
Parameters Related to Aesthetic Quality

Parameter	Concentration*
Chloride	250
Colour	5 (TCU) **
Copper	1.0
Iron	0.3
Manganese	0.05
Methane	3 L/m³
Odour	Inoffensive
Organic Nitrogen***	0.15
Phenols	0.002
Sulphate	500
Sulphide	Inoffensive
Taste	Inoffensive
Temperature	15°C
Total Dissolved Solids	500
Total Organic Carbon	5.0
Zinc	5.0

* Unless otherwise indicated, the maximum desirable concentrations are expressed in mg/L

** True Colour Units.

*** Total kjeldahl nitrogen minus ammonia nitrogen.

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*OWR Act, R. S. O. 19
Section 23, Subsect

APPENDIX IV

Drinking Water Criteria

TABLE 1
MAXIMUM ACCEPTABLE LEVELS IN WATER USED FOR DOMESTIC CONSUMPTION

PARAMETER		LEVEL		REFERENCE
ALKALINITY, TOTAL as $CaCO_3$	GE	30	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
	LE	500	mg/L	
AMMONIA as N	LE	0.5	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
ARSENIC as As	LE	0.05	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
BACTERIA, FECAL COLIFORM		ND	No./dL	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
BACTERIA, TOTAL COLIFORM	LE	10	No./dL	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
BARIUM as Ba	LE	1.0	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
BORON, as B	LE	5.0	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
CADMIUM, as Cd	LE	0.005	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
CALCIUM, as Ca	LE	200	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
CESIUM-137	LE	50	Bq/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
CHLORIDE, as Cl	LE	250	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
CHROMIUM, as Cr	LE	0.05	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
COLOUR	LE	15	TCU	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
COPPER, as Cu	LE	1.0	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
CYANIDE, as CN	LE	0.2	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
FLUORIDE, as F	LE	1.5	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
HARDNESS, TOTAL as $CaCO_3$	LE	120	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
IODINE-131	LE	10	Bq/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
IRON, as Fe	LE	0.3	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
LEAD, as Pb	LE	0.05	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
MAGNESIUM, as Mg	LE	150	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
MANGANESE, as Mn	LE	0.05	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
MERCURY, as Hg	LE	1.0	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
NITRATE + NITRITE as N	LE	10.0	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
NITRITE, as N	LE	1.0	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
NTA as H_3NTA	LE	50.0	µg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA R3 73.033
OIL AND GREASE		ND	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
pH	GE	6.5		
	LE	8.5		
PHENOLIC SUBSTANCES, as PHENOL	LE	0.002	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
PHOSPHATE, TOT INORG as P	LE	0.065	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
PHOSPHATE, TOTAL as P	LT	0.100	mg/L	US. ENVIRONMENTAL PROTECTION AGENCY, 440/9-76-023
PHOSPHORUS, as P	LE	0.2	mg/L	HART, 1974, AUSTR. WAT. RES. COUNCIL TECH PAPER 7
α RADIATION, TOTAL	LE	0.02	Bq/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA R3 73.033
β– RADIATION, TOTAL	LE	0.19	Bq/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA R3 73.033
RADIUM-226	LE	1.0	Bq/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
SELENIUM, as Se	LE	0.01	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
SILVER, as Ag	LE	0.05	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
SODIUM, as Na	LE	270	mg/L	HART, 1974, AUSTR. WAT. RES. COUNCIL, TECH PAPER 7
STRONTIUM-90	LE	10	Bq/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
SULPHATE, as SO_4	LE	500	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
SULPHIDE, as H_2S	LE	0.05	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
SURFACTANTS, as MBAS	LE	0.5	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
TEMPERATURE	LE	15	°C	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
TOTAL DISSOLVED SOLIDS	LE	500	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
TRIHALOMETHANES	LE	0.35	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
TRITIUM	LE	40 000	Bq/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
TURBIDITY	LE	5	NTU	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
URANIUM, as U	LE	20	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
ZINC, as Zn	LE	5.0	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979

APPENDIX V

Drinking Water Guidelines

ABLE 3
OBJECTIVE LEVELS IN WATER USED FOR DOMESTIC CONSUMPTION

PARAMETER		LEVEL		REFERENCE
AMMONIA, as N	LE	0.01	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
ANTIMONY, as Sb	LE	0.2	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
ARSENIC, as As	LE	0.005	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
BACTERIA, FECAL COLIFORM		ND	No./dL	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
BACTERIA, FECAL STREPTOCOCCI	LT	1	No./dL	ONTARIO MINISTRY OF THE ENVIRONMENT, 1974
BACTERIA, TOTAL COLIFORM		ND	No./dL	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
BARIUM, as Ba	LE	0.1	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
BORON, as B	LE	0.01	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
CADMIUM, as Cd	LE	0.001	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
CALCIUM, as Ca	LT	75	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
CESIUM-137	LE	5	Bq/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
CHLORIDE, as Cl	LT	250	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
CHROMIUM, as Cr	LE	0.2	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
COLOUR	LT	15	TCU	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
COPPER, as Cu	LT	1.0	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
CYANIDE, as CN	LE	0.002	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
FLUORIDE, as F	LE	1.0	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
HARDNESS, TOTAL, as $CaCO_3$	LT	120	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
IODINE-131	LE	1	Bq/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
IRON, as Fe	LT	0.05	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
LEAD, as Pb	LE	0.001	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
MAGNESIUM, as Mg	LT	50	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
MANGANESE, as Mn	LT	0.01	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
MERCURY, as Hg	LE	0.2	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
NITRATE + NITRITE, as N	LE	0.001	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
NITRITE, as N	LE	0.001	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
NTA, as HgNTA	LE	0.2	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
ODOUR		ND	TON	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
PHENOLIC SUBSTANCES, as PHENOL	LT	0.002	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
PHOSPHATE, TOT.INORG., as P	LT	0.065	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
RADIATION, TOTAL	LT	0.37	Bq/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
RADIUM-226	LE	0.1	Bq/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
SELENIUM, as Se	LE	0.002	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
SILVER, as Ag	LE	0.005	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
STRONTIUM-90	LE	1	Bq/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
SULPHATE, as SO_4	LT	150	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
SULPHIDE, as H_2S	LT	0.05	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
SURFACTANTS, as MBAS	LT	0.2	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
TASTE		ND		DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
TEMPERATURE	LT	15	°C	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
TRIHALOMETHANES	LE	0.5	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
TRITIUM	LE	4000	Bq/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
TURBIDITY	LT	1	NTU	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
URANIUM, as U	LE	1	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
ZINC, as Zn	LT	5.0	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979

C

APPENDIX C

Eldorador Resources Test Results
Radium 226 Determinations

Eldorado Resources Limited
Suite 400 255 Albert Street
Ottawa, Ont. Canada K1P 6A9
(613) 238-5222 Telex 053 3382

eldorado

May 19, 1987

C.A. Booth
Project Scientist, Mineral Resources
Ontario Research Foundation
Sheridan Park Research Community
Mississauga, Ontario
L5K 1B3

Dear Mr. Booth,

We have completed the radium-222 determinations on the four samples of leachate extract which you sent under cover of your letter to Dr. A.J. Oliver, dated May 22, 1987.

Results on these samples are as follows:

Sample identification	^{226}Ra, Bq/L
LEP87-42(KL-5)	258 ±28
LEP87-43(MW-1)	0.77± 0.09
LEP87-49(KL-5)	219 ±24
LEP87-50-(MW-1)	0.66± 0.07

These results were also given verbally to Dr. Lakshmanan yesterday.

Yours truly,

G.T. Day
Head, Support Services
Research and Development

/sjl

c.c.: AJO

C

APPENDIX D

Golder Associates:
Specific Gravity, Porosity,
Permeability and Compressive Strength Results

Golder Associates
CONSULTING GEOTECHNICAL AND MINING ENGINEERS

June 26, 1987 Our ref: 871-1159

Ontario Research Foundation
Sheridan Park Research Community
MISSISSAUGA, Ontario
L5K 1B3

ATTENTION: Mr. Craig Booth

RE: LABORATORY TESTING OF CEMENTED TAILINGS
O.R.F. Purchase Order No. 48180

Dear Sirs:

This letter reports the results of the laboratory tests which were carried out on samples of cemented tailings. These samples were delivered to our laboratory on May 13, 1987, in moulded conditions.

The tests specified to be carried out were Specific Gravity, Porosity (volume method), Permeability and Compressive Strength.

The permeability tests were carried out using a triaxial mercury/water constant head apparatus. This equipment includes a triaxial kerosene-water twin tube volume change unit on the pressurized inflow line and a burette, open to atmosphere, on the outflow line. The results of these tests, together with the porosity value determinations, are summarized on Table 1, and the permeability test data are shown on Figures 1 to 17-2, inclusive.

The undrained triaxial compression tests were carried out on samples that were a nominal 2:1 length/diameter ratio. The samples were tested with lateral pressures of 172, 342 and 689 kPa. The results of these tests are summarized on Table 2 and the test data are shown on Figures 18-1 to 26-2, inclusive.

The specific gravity test results are given on Table 3.

Based on our examination of the essentially granular materials, together with the results of the undrained compression tests, the cemented tailings are non-cohesive. Further study of the cemented tailings for this characteristic is suggested.

We trust that this information is sufficient for your immediate purposes. However, if there are any questions regarding these results, please contact us.

Yours truly

GOLDER ASSOCIATES

F. A. Rydgren

Leo R. Lahti, P. Eng.

FAR/LRL/jm

Enc: Tables 1 to 3, inclusive
Figures 1 to 26-2, inclusive

TABLE 1

SUMMARY OF CONSTANT HEAD PERMEABILITY TEST RESULTS

Sample No.	Test Date	Porosity %	Test Run	Hydraulic Gradient	Coefficient of Permeability cm/s
GP-25	87-04-13	42.2	4	343.9	8.55×10^{-6}
GP-25	87-04-14	42.2	6	343.9	3.38×10^{-7}
GP-25	87-04-14	42.2	7	343.9	1.95×10^{-7}
GP-25	87-04-16	42.2	8	343.9	3.57×10^{-8}
GP-25	87-04-20	42.2	9	343.9	3.15×10^{-8}
C-2	87-05-17	13.6	4	123.6	2.85×10^{-6}
C-2	87-05-26	17.6	4	74.3	1.95×10^{-6}
KL-5	87-05-17	38.2	4	95.5	2.67×10^{-6}
KL-5	87-05-25	36.0	4	61.7	3.71×10^{-6}
KK-1	87-05-20	29.2	4	69.6	1.26×10^{-4}
KK-1	87-05-21	29.2	8	69.6	1.14×10^{-5}
KK-1	87-05-25	29.4	4	85.9	1.35×10^{-5}
KK-1	87-05-25	29.4	8	85.9	1.91×10^{-5}
MW-2	87-05-20	23.5	4	74.5	1.17×10^{-4}
MW-2	87-05-27	21.7	4	78.6	3.53×10^{-5}
P-5	87-05-21	34.8	3	74.5	5.15×10^{-8}
P-5	87-05-28	32.3	2	88.6	6.21×10^{-8}

PERMEABILITY TESTS CARRIED OUT USING THE CONSTANT PRESSURE MERCURY/WATER TRIAXIAL APPARATUS.

TEST RUN INDICATES NUMBER OF TEST RUNS USED TO DETERMINE THE COEFFICIENT OF PERMEABILITY TEST RESULTS.

POROSITY DETERMINED BY VERNIER MEASUREMENTS OF VOLUMES.

TABLE 2

SUMMARY OF UNDRAINED TRIAXIAL COMPRESSION TEST RESULTS

Sample No.	Test Date	Dry Unit Weight kN/m^3	Compression Stress kPa	Confining Pressure kPa
KK-1-A	87-05-15	19.07	2724.4	172.2
KK-1-B	87-05-15	18.88	2142.4	344.5
KK-1-C	87-05-17	18.69	2854.7	689.0
MW-2-A	87-05-15	17.91	3312.8	172.2
MW-2-B	87-05-15	19.45	2577.4	344.5
MW-2-C	87-05-17	19.61	5241.9	689.0
P-5-A	87-05-15	16.36	1159.7	689.0
P-5-B	87-05-15	16.44	614.3	344.5
P-5-C	87-05-15	17.78	1502.1	172.2

TABLE 3

SUMMARY OF SPECIFIC GRAVITY TEST RESULTS

Sample No.	Specific Gravity
GP-25	2.30
C-2	1.96
KL-5	2.28
KK-1	2.49
P-5	2.38

SPECIFIC GRAVITY TESTS CARRIED OUT USING KEROSENE.

THE MEASUREMENT OF SOIL PROPERTIES IN THE TRIAXIAL TEST

By

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used to record the volume of water flowing, Fig. 101. If the permeability is very low a volume-measuring apparatus is interposed at one end.

Test results show that, for compacted fill materials, the value of the coefficient of permeability, calculated from the coefficient of consolidation and the volume change in the dissipation test, is in satisfactory agreement with the direct measurement of permeability.

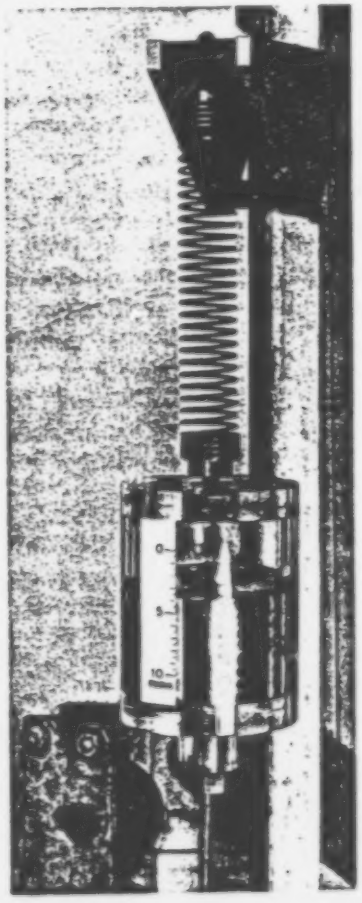

Fig. 101. Use of the self-compensating mercury control for the measurement of volume change

6. Tests with No Lateral Strain (K_o-Tests)

It is sometimes of practical importance, as well as of research interest, to carry out triaxial tests under conditions of zero lateral strain. Tests of two types are performed:

(i) Undrained tests on partly saturated samples, either of natural strata or of compacted fill, are carried out to provide a direct measurement of the pore-

is also measured. The cell pressure is finally decreased under undrained conditions.

The sample is weighed on removal from the cell, and several specimens for water-content determination are taken.

The test itself presents no special difficulty. Two points may, however, be noted. If the laboratory is subject to temperature fluctuations the accuracy of

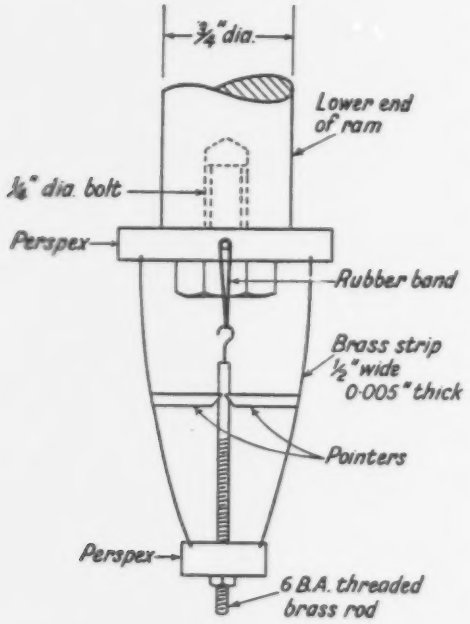

Fig. 100. Indicator used in measuring axial strain during consolidation under equal all round pressure

the volume measurements may not be satisfactory. In this case, and in any accurate determination of small strains, the length changes may also be measured. In the small cell the seamless Perspex tube is sufficiently true for this to be done optically with a vernier telescope. In the large cell the loading ram is used, its lower end being fitted with a sensitive indicator (Fig. 100) to show contact with the cap without any significant load. Secondly, in clay fill materials compacted at low moisture contents the pore pressure tends to be erratic, as indicated on p. 100.

The accuracy of the estimate of coefficient of consolidation in partly saturated soils can be increased by limiting the dissipation stage to the range of pore-pressure values which will apply in practice. Drainage is in this case permitted against a specified back pressure maintained by a constant-pressure system.

The direct measurement of permeability is made, at low values of pore pressure, by connecting a burette on a flexible lead to each end of the sample and maintaining a constant head by periodic adjustment in level (as in Fig. 83). At high pressures a constant-pressure system is used at each end of the sample. The cylinders of the mercury-type pressure control are fitted with a scale and

(3) When required, a direct measurement of permeability can be made at any value of the pore pressure corresponding to field conditions. This is of importance in partly saturated soils, where the degree of saturation is greatly increased at higher pore pressures. Elevation of the pore pressure can in fact be conveniently used to produce full saturation in samples in which it cannot be achieved by prolonged flooding.

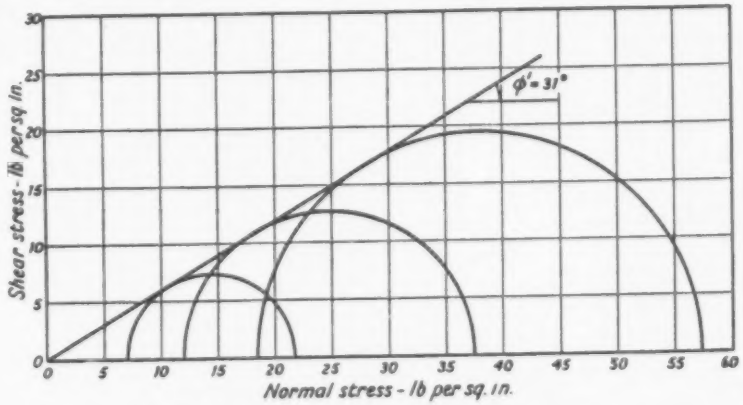

Fig. 95. Mohr envelope for drained tests on raw sugar

The test is usually carried out on 4-in. diameter samples. A sample height of 8 in. is used where the coefficient of consolidation is high; a height of 4 in. being used for soils of low permeability, to reduce the duration of the test. Undisturbed samples of clays of high plasticity may be tested in the small cell, a minimum sample height of $1\frac{1}{2}$ in. being used.

The test procedure follows that for the undrained test with pore-pressure measurement (p. 98); with the addition of a saturated porous disc on top of the sample and a de-aired drainage connexion to the loading cap. No side drains are used. If drainage is to be permitted to atmospheric pressure, the connexion is taken to a burette (a twin burette is used for partly saturated soils). The layout is illustrated in Fig. 96.

If a back pressure is to be applied during the dissipation stage, the alternative volume measuring devices described in PART II, Section 4, p. 63, are substituted for the burette.

After the sample has been prepared and the cell assembled the zeros of the volume-change and pore-pressure devices are checked. With the drainage valve a_2 closed the cell pressure is increased in several steps to the required value, the volume change and pore pressure being read after each step when the values have become steady. Where an accurate estimate of volume change is being made, the relation between pore pressure and volume change during the intermediate steps permits the determination of the initial volume of air trapped between the rubber membrane and the sample (Appendix 5). From the ratio of pore-pressure change to cell-pressure change values of the parameter B are obtained. This stage of the test also gives the relationship between volume change and effective stress under undrained conditions.

The drainage valve a_2 is then opened, and readings are taken of pore pressure,

Gregory W. Carpenter[1] and Richard W. Stephenson[2]

Permeability Testing in the Triaxial Cell

REFERENCE: Carpenter, G. W. and Stephenson, R. W., **"Permeability Testing in the Triaxial Cell,"** *Geotechnical Testing Journal*, GTJODJ, Vol. 9, No. 1, March 1986, pp. 3-9.

ABSTRACT: It has been suggested that a triaxial shear test chamber can be used to measure the permeability of low permeability soils. To verify this, the influence of a number of test parameters on the measured coefficient of permeability was investigated. Results indicate such permeability tests should be performed on samples having a minimum diameter of 71.1 mm (2.8 in.) and a length to diameter ratio of 0.5 to 1.0. It was found that a permeant consisting of 1 g of magnesium sulfate heptahydrate (epsom salt) dissolved in 1 L of deaired, distilled water is adequate for general permeability testing. The triaxial, falling head permeability test should be conducted at a gradient that results in an applied effective stress at the outflow end of the sample less than the preconsolidation stress of the material. It was found that with very careful trimming, the influence of the smear zones created at the ends of the samples during the trimming process can be minimized.

KEYWORDS: soil tests, permeability, triaxial tests, clays

In conducting a falling head, permeability test, a soil sample is often confined in a rigid ring or cylinder. This method of confinement sometimes results in permeant flow along the interface between the ring and the sample. To correct this deficiency, it has been proposed that a triaxial cell be used as a permeameter [*1*]. In a triaxial cell, a flexible membrane replaces the rigid confining ring and is kept tightly compressed against the sides of the sample by pressure applied to the fluid in the cell. This minimizes the possibility of seepage along the interface. Another advantage is that the sample can be consolidated to its in-situ stress condition or other desired stress states before it is tested.

This technique, which incorporates back-pressure saturation, has been used to confirm that Darcy's law is valid for soil, if the soil is completely saturated [*2*]. The same technique has been used to test rock cores [*3*], which are not subject to testing with water but with natural gas, petroleum products, and grout mixtures. The conclusion is that the procedure can be a valuable evaluation tool for solving petroleum engineering problems and high-pressure rock grouting problems. This triaxial cell permeability testing technique has been used in conjunction with earlier work [*4,5*] to show that the coefficient of permeability can quickly be obtained by using a pressure-stressed metal diaphragm (small volume of flow).

This paper documents the use of a triaxial cell for hydraulic conductivity characteristics of fine grained soils. During the investigation, factors, which may influence the coefficient of permeability as determined by the triaxial, falling head, permeability testing technique, were evaluated.

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Experimental Program

Several clay soils were investigated as possible choices for use in the testing program. The desired soil required a coefficient of permeability of approximately 10^{-8} cm/s in a reconstituted form. The clay finally chosen for testing was a clay obtained from an operating clay mine in Bloomfield, MO. This clay, which is being mined from the Porter Creek Formation, is composed of about 55 to 65% smectite, 10 to 20% illite, 10 to 20% kaolinite, 5 to 15% quartz, and less than 0.001% heavy minerals. A chemical analysis of the material by the Southern Clay Company indicates the major constituents are potassium and magnesium with very small amounts of calcium and sodium.

Specimen Preparation

A static consolidation technique was used to prepare the specimens for study [*6*]. The clay was pulverized in a mortar with a pestle until it could be passed through a 425-μm (No. 40) sieve. The sieved clay for each specimen was mixed by hand with enough of the epsom salt permeant chosen for the study to result in a moisture content of 105%. This is well above the soil's liquid limit of 98 evaluated using the epsom salt solution. This mixture was then allowed to stand covered for a period of 48 h. Each sample was then placed in a 101.6-mm (4.0-in.) diameter consolidation cell. As the sample was placed in the consolidation cell, air was trapped between the particles of clay. To remove as much of this air as possible, a 74.6-W (0.1-hp) vibratory motor attached to a 762-mm (30-in.) piece of 25.4- by 25.4-mm (1- by 1-in.) aluminum angle section was inserted into the sample. The vibration of the angle section densified the clay and helped to remove the air. A piston with a porous stone and filter paper was then inserted, and the rest of the consolidation cell was assembled. The specimen was then loaded sequentially with 13.4, 26.8, 41.2, 68.0, 94.8, and 177.2 kPa (1 kPa = 0.0104 tons/ft^2). Small increments of stress were employed to prevent any clay from being extruded past the piston.

Each sample was X-rayed on two perpendicular planes after being removed from the consolidation cell to determine if it was suitable for use. Some of the specimens were rejected when the X-ray results indicated that they contained large voids.

All specimens used for testing were trimmed from these 101.6-mm samples. Specimens prepared in this manner exhibited uniform grain size distribution and unit weight characteristics. The

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dry unit weights of the specimen varied between 13.0 to 13.7 kN/m^3 (85.9 to 87.3 lb/ft^3).

Permeant Used for Testing

Because of a concern about the variations in permeability testing caused by changes in the permeant used, a standardized permeant was used throughout the study. The use of permeants, which are not controlled, may result in the leaching or replacement of ions within a soil [*7–10*], and this may ultimately lead to changes in the soil's characteristics.

Because one of the principal chemical constituents in the clay used in the study is magnesium, a permeant containing magnesium ions was used in all the tests. This permeant consisted of deaired, distilled water and 1 g/L of magnesium sulfate heptahydrate (epsom salt). This solution, when mixed with the clay, resulted in samples that were highly flocculated and represented the most permeable type of soil structure. Because the clay was flocculated, any change in ions in the permeant, in conjunction with the pressures applied to the sample, could easily have resulted in the collapse of the flocculated structure into a more dispersed form and thereby influenced the flow measurements.

It was reasoned that if the ions present in the permeant would tend to result in a flocculated structure then this permeant could be used universally. If the structure of the test sample was flocculated, it would not disturb this structure. If the test sample had a dispersed structure, then the structure could not go from a dispersed to a flocculated form without a remixing of the material to allow for the formation of a completely new flocculated structure.

Triaxial Permeability Testing Apparatus

A special triaxial cell was used to confine the samples during the tests. An air over water interface chamber was used to pressurize the cell. The standtubes, which were used for back-pressure saturation and for reading the inflow and outflow from the samples, were constructed of 1000 mm (39.37 in.) lengths of 9.53-mm (0.375-in.) outside diameter plexiglass tubes. This size constituted an inside cross-sectional area of 31.15 mm^2 (0.04828 in.^{2}). All pressures were applied to the system with compressed air that had been passed through two pressure tanks and two pressure regulators (to prevent pressure fluctuations) before being applied to the system. All pressures (that is, cell pressure as well as inflow and outflow pressures) were monitored with pore-pressure transducers. The volume of the standtubes was carefully calibrated at the operating pressures to insure accurate and repeatable measurement of flow volumes. Figure 1 shows the entire triaxial cell permeability apparatus that was used during the study.

Test Procedure, Data Measurements, and Calculations

A sample with the test dimensions was mounted in the permeameter and wrapped with a rubber membrane. The cell was filled with deaired tap water, the inflow and outflow standpipes were charged with permeant, and the cell connected to the cell pressure line. The system was then deaired using vacuum and flushing techniques. The specimen was then subjected to back-pressure saturation in the manner consistent with that done for normal triaxial shear strength tests. Following back-pressure saturation, the cell pressure was increased to its test pressure, and the sample allowed to consolidate. Following consolidation and back-pressure saturation, the inflow and outflow standtube readings were recorded and the volume change of the sample was calculated. These results were used to calculate the final pore volume of the specimen.

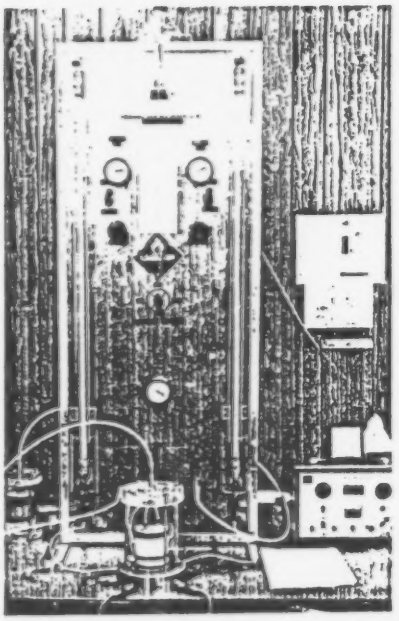

FIG. 1—*Permeability testing equipment.*

The test gradient was established across the specimen by increasing the air pressure in the inflow standtube while maintaining the outflow line pressure at the back-pressure value. Initial readings of in and out standtube permeant levels were taken. As flow occurred, readings were taken at intervals of every half pore volume of flow until the permeability stabilized.

The coefficient of permeability (or simply, permeability as used in this report) k is computed by first calculating the coefficient of hydraulic conductivity K, by the falling head equation, and then converting it into permeability by using the relative viscosity and relative density of the permeant, compared to that of the standard permeant. The hydraulic gradient is computed in terms of head of water in all cases. The equations are given below

$$K = \frac{aL}{A(t_i - t_f)} \ln(h_i/h_f) \tag{1}$$

where

K = hydraulic conductivity, cm/s,
a = cross-sectional area of stand pipe, cm^2,
L = length of the sample, cm,
A = cross-sectional area of sample, cm^2,
$t_i - t_f$ = elapsed time, s,
h_i = initial head difference between inflow and outflow stand tube (permeant + air pressure), cm of water, and
h_f = final head difference between inflow and outflow stand tube (permeant + air pressure), cm of water.

and

$$k = \frac{K \nu_r}{\rho_r} \tag{2}$$

where

k = permeability, cm/s,
ν_r = relative viscosity (dimensionless), and
ρ_r = relative density (dimensionless).

The relative viscosity and relative density were computed by dividing the absolute viscosity and density of the permeant by those of the standard permeant, which, because of its very low concentration (0.004 N), was considered to have the same viscosity and density as distilled water at 25°C.

Variables Affecting the Triaxial Permeability Results

There are several variables that may be investigated separately to determine the influence of each on the measured coefficient of permeability. Each of these are discussed separately below.

Boundary Influences

For determining boundary influences, a sample within a flexible membrane is confined in the triaxial cell. This membrane is held against the sides of the sample by cell pressure in excess of the maximum applied internal pore pressure. The contact zone between the membrane and the sample may thus be affected so that the cross-sectional area of the sample is decreased and the flow of the permeant thereby impeded. Because according to Darcy's law, it is assumed that the flow front of permeant, as it moves through the sample, lies in a plane that is perpendicular to the direction of flow, it is important to determine the influence the material has on the boundary of the flow front.

To determine this influence, samples of three different diameters were studied. The diameters were 102, 71.1, and 35.6 mm (4.0, 2.8, and 1.4 in.). A gradient of 200 was used to force the standardized permeant through all three samples. Fluorescein dye was added to the permeant so that the flow front could be visually examined. After each of the three samples had been partially permeated, it was removed from the triaxial cell and cut in half along the axis of the cylinder. It was then allowed to air dry for approximately 24 h. A sharp knife was used to trim the cut surface of each to remove any disturbed portions. The degree of penetration and shape of the flow front of dyed permeant were visible but difficult to define with any precision. Because the dye used in the permeant is fluorescent, the samples were examined in a dark room with an ultraviolet light.

Smear Zones on Sample Ends

The ends of permeability samples must be trimmed before they are tested. This trimming process creates disturbed zones that may impede flow [*11*]. The extent to which flow is impeded is a function of the trimming tool used, the properties of the soil, that is, how susceptible the soil is to smearing, and the care and skill of the operator.

To evaluate the influence of sample disturbance resulting from trimming, an intact sample was tested first in the triaxial permeability apparatus. It was then removed and cut perpendicular to its vertical axis. The same procedure was used as for trimming the ends. Four such cuts were made in each of two samples, one with a diameter of 102 mm (4.0 in.) and the other with a diameter of 71.1 mm (2.8 in.). Only three cuts were made in a sample with a diameter of 35.6 mm (1.4 in.) because of its small size. Each of these cuts was the equivalent of a trimmed surface at each end of a test sample. After the samples were cut, they were again tested. The difference in the measured permeabilities could then be attributed to the influence of the trimmed surfaces. The influence of different trimming techniques and tools was not investigated however.

Gradient Magnitude

Nine samples (three of each of the three selected diameters) were tested at four different gradients ranging from 50 to 300. Each sample was tested at each gradient until steady state flow was established. Steady state flow is defined as equal readings of permeant inflow and outflow.

Length-to-Diameter Ratio

The influence of the length-to-diameter ratio was examined by performing permeability tests on samples of five different length-to-diameter ratios for each of the three selected diameters. Each of the tests was performed at a gradient of 200, and each test was conducted long enough to establish steady state flow.

Duration of Testing

The effect of test duration was evaluated by testing one sample of each of the three selected diameters for an extended period of time. Gradients of 25 and 200 were used to cover the range of gradients studied. The samples were tested first with the lower of the two gradients after which the gradient was increased to 200. The purpose was to evaluate the influence of microorganic growth or other long-term effects within the samples under prolonged periods of testing [*12*].

High Effective Stresses at Outflow End

When a permeability test is performed in a triaxial cell, there is no way to avoid elevated effective stresses at the outflow end of the sample (Fig. 2). Tests were conducted to examine this problem and its influence on the measured coefficient of permeability.

Degree of Saturation

When a sample is confined in a triaxial cell, the saturation of the sample is usually determined by evaluating the B coefficient. The B coefficient is defined as the ratio of the pore-pressure increase within the test specimen to the corresponding increase in the cell pressure ($B = \Delta u/\Delta \sigma_c$). In general, a B coefficient of 1.0 indicates complete specimen saturation. For permeability testing, the highest coefficient of permeability is measured when the sample is 100% saturated. To ensure that the test samples used in the study were saturated at the time of testing, each was back-pressure saturated, and the B coefficient was checked before the start of each test. Because the samples were consolidated from a slurry with a moisture content that exceeded the liquid limit, they were nearly saturated at the outset. Each sample was subjected to a back pressure of 276 kPa (40 lb/in.^{2}). For all samples, this resulted in a B coefficient of 0.94 or greater. With the B coefficients in excess of 0.94, all of the samples were believed to be in a saturated state at the time of testing.

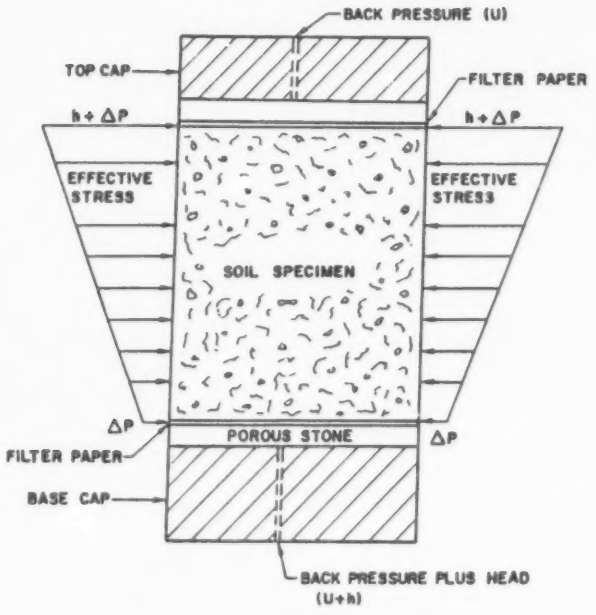

FIG. 2—*Effective stress distribution on test specimen.*

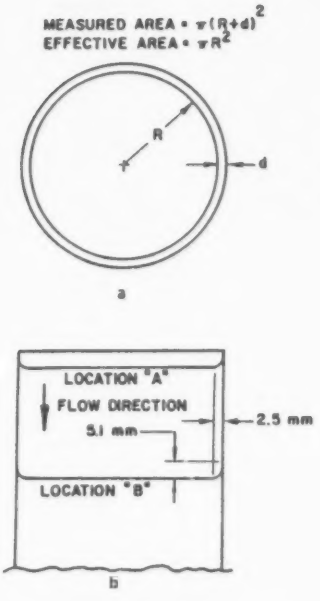

FIG. 3—*Flow front configuration.*

Initially, there was some concern that the degree of saturation of the samples might decrease during the testing process because of the pressure decrease on the permeant as it flowed through samples. Consequently, some of the samples were checked after they were tested to determine the B coefficient, and, hence, the degree of saturation had been changed.

Results

Boundary Influences

It was observed that the plane of the permeant's flow front was approximately perpendicular to the vertical axes of the sample cylinders with a small amount of distortion near the boundaries. This distortion was estimated to be about 2.5 mm (0.10 in.) regardless of the diameters of the samples. It was also evident that the intensity of the dye in the permeant attenuates the farther the permeant penetrates a sample.

By using 2.5-mm estimate of the boundary effect, the total effect, which might be attributed to boundary effects, was evaluated. The values arrived at are maximum values, if it is assumed that the flow is completely restricted along the boundaries.

From Darcy's law and Fig. 3, a decrease in the effective area of flow results in an underestimation of the coefficient of permeability by a percentage equal to $[1 - R^2/(R+d)^2]\,100$. When this percentage is calculated for the three specimen diameters used in the study, the results are 26.5% for the 35.6 mm (1.4 in.) diameter, 13.8% for the 71.1 mm (2.8 in.) diameter, and 9.8% for the 101.6 mm (4.0 in.) diameter.

After the flow front is initially formed as shown in Fig. 3*b* (Location A), it progresses through the sample (Location B) without changing its configuration. It was concluded that the only time any underestimation of the coefficient of permeability might occur is during the initial formation of the flow front. As shown in Fig. 3*b*, the flow front's distortion occasioned by boundary effects extends back about 5.1 mm (0.20 in.) into the sample. This indicates that at a gradient of 200, the restricted flow area may have an influence on the calculated coefficient of permeability for a period of about 14 h. Tests of shorter duration would produce significant errors because of the boundary effects.

Smear Zones on Sample Ends

The results of the influence that smear zones on sample ends have on permeability are shown in Table 1. All of these tests were conducted at a gradient of approximately 200, and the flow before and after the samples were cut was allowed to continue until a steady state condition developed. From the results, it is evident that for the particular clay tested, the sample ends, when prepared with a fine, tensioned wire, reduced the coefficient of permeability by about 5%. The two larger samples, which had four cut surfaces, both showed a reduction of about 18 to 20%. The 35.6-mm (1.4-in.) diameter samples exhibited a reduction in the coefficient of permeability of about 43% for three cuts, or the equivalent of about a 14% reduction for the trimmed surfaces at the ends of the specimen. As

TABLE 1—*Summary of end effect data.*[a]

Number of Cuts	Specimen Dimensions, mm	k Before Cuts, cm/s	k After Cuts, cm/s
3	35.6 diameter 53.3 length	16.7×10^{-8}	9.6×10^{-8}
4	71.1 diameter 108.0 length	5.1×10^{-8}	4.2×10^{-8}
4	101.6 diameter 152.4 length	5.0×10^{-8}	4.0×10^{-8}

[a] 1 in. = 2.54 cm.

previously stated, this latter sample, because of its small size, was much more difficult to work with during the cutting process, though the cuts were carefully made. Consequently, the portions disturbed during the cutting process may have been responsible for the larger indicated reduction in the coefficient of permeability.

Gradient Magnitude

The coefficient of permeability when determined in the triaxial permeability apparatus was found to decrease as the gradient was increased. Figure 4 represents the measured values of the coefficient of permeability as a function of the gradient used during testing. The decrease in permeability may be attributed to the high effective stress applied to the outflow end of the sample. This is discussed more fully below.

If the relationship between the measured coefficient of permeability at a gradient of 200 and the length of the sample is examined (Fig. 5), it can be seen that the coefficient of permeability decreases with an increase in the length of the sample. Although the data are scattered, it appears that most of the decrease can be attributed to the increase in applied effective stress at the outflow end of the sample. This increase in effective stress is necessary to achieve the same gradient as the length of the sample is increased.

Length-to-Diameter Ratio

The results of the tests performed to evaluate the influence of the length to diameter ratio are presented in Fig. 6. These results indicate a slight decrease in the measured coefficient of permeability as the length to diameter ratio is increased except for the small, 35.6-mm (1.4-in.) diameter samples. Figure 6 also shows that the

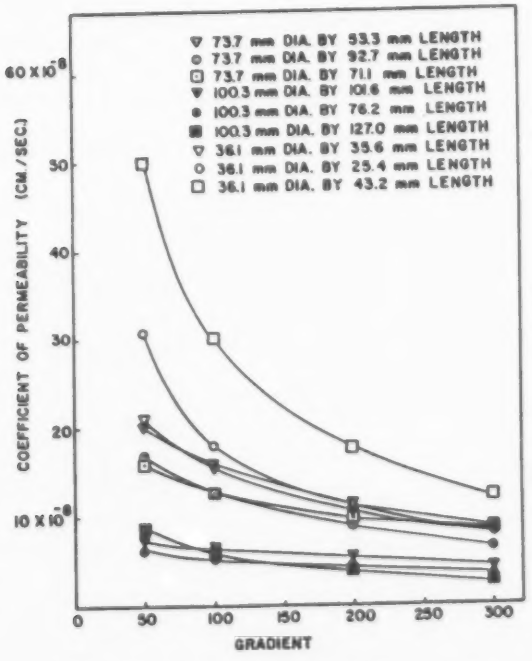

FIG. 4—*Gradient versus coefficient of permeability.*

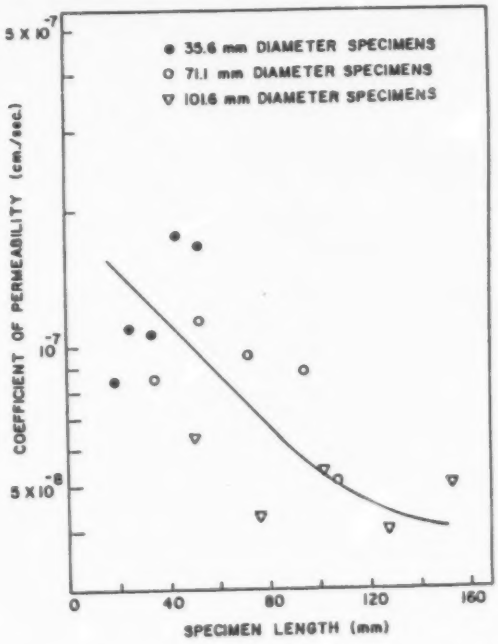

FIG. 5—*Specimen length versus coefficient of permeability (i = 200).*

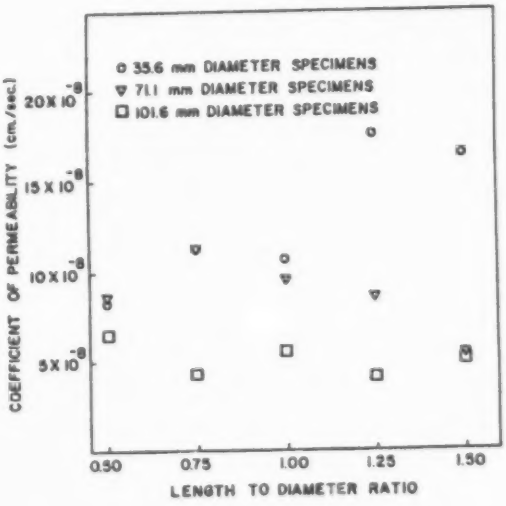

FIG. 6—L/D *versus coefficient of permeability (i = 200).*

smaller the diameter of the sample, the greater the deviation in the measured value of the coefficient of permeability from the average.

The increased amount of data scatter in the measured value of the coefficient of permeability for the small diameter sample may be attributed to the fact that it was a less representative sample, and this increased the number of minor measurement errors, which influenced the results. The increased data scatter may also be attributed to the fact that with the small diameter sample the ratio of disturbance to size may be a much greater influence on the measured value than on the large diameter samples.

The tendency for the measured coefficient of permeability to decrease with an increase in the length to diameter ratio is probably caused by a necessary increase in the effective stress at the outflow end of a sample so that it retains the same gradient as a longer sample. This effect is discussed below.

Duration of Testing

The results of test duration indicate that there is a tendency for the measured coefficient of permeability to become stable after a period of about 1 to 2 h. After the period required for the attainment of steady state flow, there is a tendency for the measured coefficient of permeability to decrease slightly with time (Fig. 7). This decrease is in all probability due either to the presence of microorganisms or to the effects of secondary consolidation or both. No antibacterial agent was added to the permeant because it was feared that the agent might have a greater influence on the permeability than on the microorganisms. Apparently, the small amount of decrease in the measured coefficient of permeability occasioned by the extension of testing time had only a minor effect on the results in comparison with the many other testing problems and variables. However, no microbe population count was conducted so the presence or absence of microbes was not verified.

High Effective Stress at Outflow End

Figure 8 shows the experimental results of the relationship between volumetric strain and the applied effective stress at the outflow end of a sample. This indicates that when the applied stress at the outflow end exceeds the pre-consolidation pressure, the relationship becomes nonlinear. Although no measurement of volumetric strains were taken during this study, when the applied effective stress at the outflow boundary exceeds the pre-consolidation pressure, the soil is in transition from a preconsolidated state to a consolidated state and experiences increased strain. The figure also shows that the curves have similar slopes. This implies sample reproducibility.

The conclusion is that samples tested in a triaxial falling head permeability apparatus should be tested at a gradient that results in an applied effective stress at the outflow end of the sample that is less than the preconsolidation pressure. The proper gradient can be determined by performing permeability tests at several gradients and plotting the data of the volumetric strain-applied effective stress at the outflow end. Based on the results of this study, if the relationship is linear, one is assured that the applied effective stress at the outflow end does not exceed the preconsolidation pressure of the material.

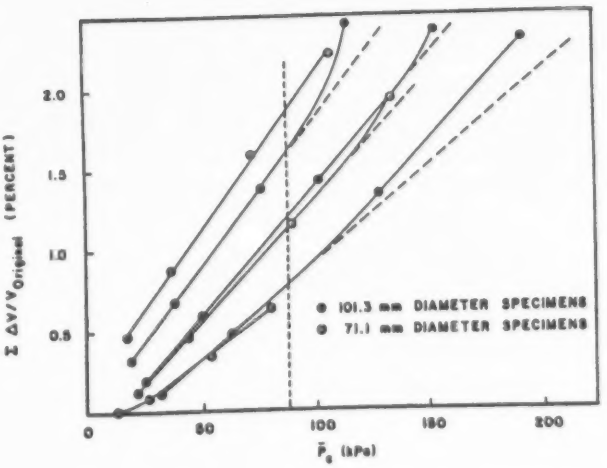

FIG. 8—$\Delta V/V$ *versus applied effective stress at outflow end.*

Figure 9 depicts the relationship between the coefficient of permeability and the applied effective stress at the outflow end of a sample. The curve indicates that the measured coefficient of permeability is much less sensitive to changes in the applied effective stress for 102-mm (4.0-in.) diameter samples as the applied effective stress is increased but is much less pronounced. For the clay used in the present study, the test data for the 71.1 mm (2.8 in.) diameter samples resulted in a measured coefficient of permeability that was about twice that of the 102-mm (4.0-in.) diameter samples when the gradient for the applied effective stress at the outflow end was equal to the preconsolidation pressure.

Degree of Saturation in Permeability

In general, the *B* coefficient tends to increase slightly during testing, although a few samples showed a very slight decrease. Because

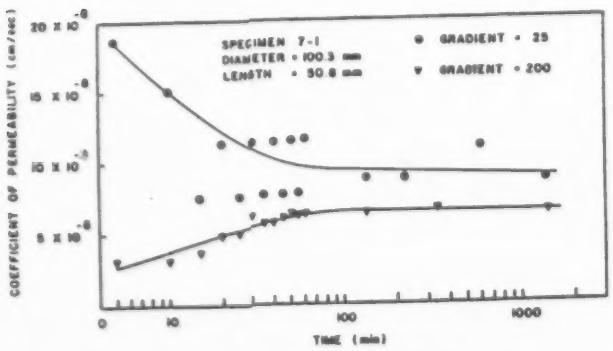

FIG. 7—*Coefficient of permeability versus testing time.*

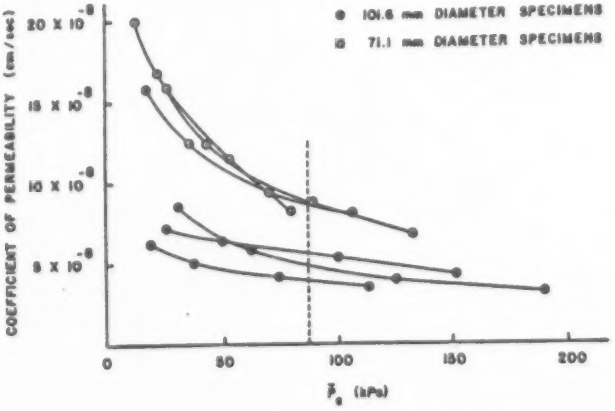

FIG. 9—*Coefficient of permeability versus applied effective stress at outflow end.*

at the termination of the testing process, none of the samples had a *B* coefficient of less than 0.94, it was assumed that the samples were fully saturated for the duration of the tests.

Conclusions and Recommendations

1. A standardized permeant should be used for all permeability testing where comparisons are to be made between different soils or soils with different physical properties such as density or structure. (The permeant used in the present study seems to be suitable, but in special cases, it may be desirable to use another type of permeant as well as a standard to determine the effect of changes at a particular site.) This is so because of the influence of permeant viscosity, density, and chemistry on the measured permeability and its reactions with the clay under study.

2. Back-pressure saturation is essential if a permeability test is to predict soil permeabilities at a particular site and for comparative study of different soils caused by the influence of degree of saturation on measured flow rates.

3. Based on this study, large specimens yield more consistent and repeatable results. Therefore, large diameter specimens are preferred for permeability testing.

4. Permeability specimens tested in a triaxial, falling head, permeability apparatus should have a length to diameter ratio of between 0.5 and 1.0.

5. The gradient used should not result in an applied effective stress at the outflow end of the sample that is in excess of the preconsolidation stress of the material.

6. Data should be collected during any triaxial, falling head, permeability test to ensure that steady state flow conditions exist before the coefficient of permeability is measured.

References

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TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 1 OF 1

FIGURE 1

BOREHOLE NUMBER
SAMPLE NUMBER GP-25 (run #1-#4 inclusive)
SAMPLE LOCATION
SAMPLE TYPE Cemented Tailings

PROJECT 871-1159

Ontario Research Foundation /Tailings /Ontario

ORIGINAL: LENGTH cm	1.840	TESTED: AREA cm2	10.75	WET WEIGHT gm	28.7
DIAMETER cm	3.700	LENGTH cm	1.84	DRY WEIGHT gm	26.3
AREA cm2	10.753	PRESSURE kPA	6.89	VOLUME WATER cc	2.4
VOLUME cc	19.786	HYDRAULIC GRADIENT (p/l)	343.85		

WATER CONTENT initial %	2.40	SPECIFIC GRAVITY	2.300	POROSITY (initial) Vv/Vo %	42.21%
WATER CONTENT final %	16.40	VOLUME SOLIDS cc	11.435		
UNIT WEIGHT kN/m3	14.22	VOLUME VOIDS cc	8.352		
DRY UNIT WEIGHT kN/m3	13.89	VOID RATIO	0.730		
lb/ft3	88.39	SATURATION %	28.737		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value

PERMEABILITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Effective Confining Pressure Base kPa
68.9	62.0	0.0		62.01	6802.661	6.9	68.9

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	INFLOW Vc cc	INFLOW aVc cc	OUTFLOW Vc cc	OUTFLOW aVc cc	DAILY PERMEABILITY RESULTS INFLOW cm/s	DAILY PERMEABILITY RESULTS OUTFLOW cm/s
87-04-13	15:27	0	0	81.40	0.0	24.20	0.0		
87-04-13	15:36	9.0	540.0	57.20	24.20	3.80	20.40	1.21E-05	1.02E-05
87-04-13	15:44	8.0	0.0	59.20	0.00	21.50	0.00		
87-04-13	15:51	7.0	420.0	40.60	18.60	0.00	21.50	1.20E-05	1.38E-05
87-04-13	16:01	8.0	0.0	42.40	0.00	22.30	0.00		
87-04-13	16:13	12.0	720.0	64.50	22.10	0.00	22.30	8.30E-06	8.30E-06
87-04-13	16:16	8.0	0.0	64.40	0.00	22.50	0.00		
87-04-13	16:28	12.0	720.0	87.40	23.00	0.00	22.50	8.64E-06	8.45E-06

COEFFICIENT of PERMEABILITY,k, cm/s

TOTAL FLOW

MINUTES		
48	INFLOW,k	4.10E-05
	OUTFLOW,k	4.09E-05
	AVERAGE,k	4.10E-05

NOTES

PART 1

MINUTES			
12	INFLOW,k	1.21E-05	cm/s
	OUTFLOW,k	1.02E-05	cm/s
	AVERAGE,k	1.12E-05	cm/s

PART 2

MINUTES			
12	INFLOW,k	8.64E-06	cm/s
	OUTFLOW,k	8.45E-06	cm/s
	AVERAGE,k	8.55E-06	cm/s
AVERAGE,k USE FOR ANALYSES		8.55E-06	cm/s

Data by F.A.R.

Golder Associates

TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 1 OF 2

FIGURE 2-1

BOREHOLE NUMBER
SAMPLE NUMBER GP-25 (run #6)
SAMPLE LOCATION
SAMPLE TYPE Cemented Tailings

PROJECT 871-1159

Ontario Research Foundation /Tailings /Ontario

ORIGINAL:	LENGTH cm	1.840	TESTED:	AREA cm2	10.75	WET WEIGHT gm	28.7
	DIAMETER cm	3.700		LENGTH cm	1.84	DRY WEIGHT gm	26.3
	AREA cm2	10.753		PRESSURE kPA	75.79	VOLUME WATER cc	2.4
	VOLUME cc	19.786	HYDRAULIC GRADIENT (p/l)		343.85		

WATER CONTENT initial %	2.40	SPECIFIC GRAVITY	2.300	POROSITY (initial) Vv/Vo %	42.16%
WATER CONTENT final %	16.40	VOLUME SOLIDS cc	11.443		
UNIT WEIGHT kN/m3	14.22	VOLUME VOIDS cc	8.343		
DRY UNIT WEIGHT kN/m3	13.89	VOID RATIO	0.729		
lb/ft3	88.39	SATURATION %	28.527		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value

PERMEABILITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Base kPa
137.8	62.0	0.0		62.81	6882.661	75.8	137.8

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	INFLOW Vc cc	INFLOW aVc cc	OUTFLOW Vc cc	OUTFLOW aVc cc	DAILY PERMEABILITY RESULTS INFLOW cm/s	DAILY PERMEABILITY RESULTS OUTFLOW cm/s
87-04-14	11:35	0	0	43.70	0.0	22.70	0.0		
87-04-14	11:40	5.0	300.0	44.70	1.00	21.60	1.10	9.02E-07	9.92E-07
87-04-14	11:48	13.0	780.0	45.40	1.70	20.90	1.80	3.94E-07	3.94E-07
87-04-14	12:00	25.0	1500.0	46.20	2.50	20.00	2.70	3.01E-07	3.38E-07
87-04-14	12:07	32.0	1920.0	46.90	3.10	19.50	3.20	3.86E-07	3.22E-07
87-04-14	12:14	39.0	2340.0	47.20	3.50	19.30	3.70	2.58E-07	3.22E-07

COEFFICIENT of PERMEABILITY,k, cm/s

TOTAL FLOW

MINUTES		
39	INFLOW,k	4.48E-07
	OUTFLOW,k	4.74E-07
	AVERAGE,k	4.61E-07

NOTES

PART 1

MINUTES			
7	INFLOW,k	2.58E-07	cm/s
	OUTFLOW,k	3.22E-07	cm/s
	AVERAGE,k	2.90E-07	cm/s

PART 2

MINUTES			
34	INFLOW,k	3.31E-07	cm/s
	OUTFLOW,k	3.45E-07	cm/s
	AVERAGE,k	3.38E-07	cm/s
AVERAGE,k USE FOR ANALYSES		3.38E-07	cm/s

Data by F.A.R.

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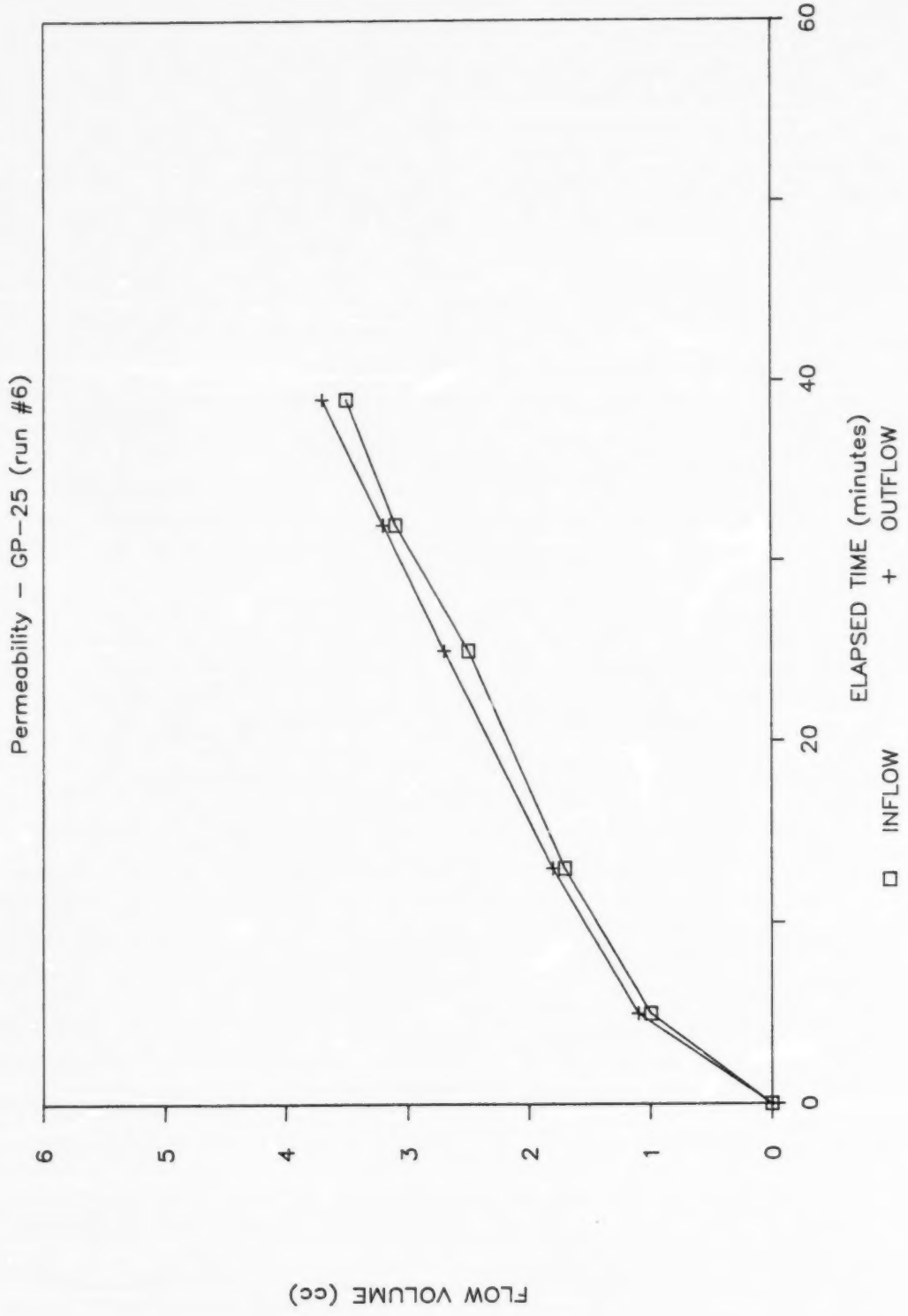
TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST
SHEET 2 OF 2

FIGURE 2-2



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TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 1 OF 2

FIGURE 3-1

BOREHOLE NUMBER — PROJECT 871-1159
SAMPLE NUMBER GP-25 (run #7)
SAMPLE LOCATION — Ontario Research Foundation /Tailings /Ontario
SAMPLE TYPE Cesented Tailings

ORIGINAL:	LENGTH cm	1.840	TESTED:	AREA cm2	10.75	WET WEIGHT gm	28.7
	DIAMETER cm	3.700		LENGTH cm	1.84	DRY WEIGHT gm	26.3
	AREA cm2	10.753		PRESSURE kPA	75.79	VOLUME WATER cc	2.4
	VOLUME cc	19.786		HYDRAULIC GRADIENT (p/l)	343.85		

WATER CONTENT initial %	2.40	SPECIFIC GRAVITY	2.300	POROSITY (initial) Vv/Vo %	42.16%
WATER CONTENT final %	16.40	VOLUME SOLIDS cc	11.443		
UNIT WEIGHT kN/m3	14.22	VOLUME VOIDS cc	8.343		
DRY UNIT WEIGHT kN/m3	13.89	VOID RATIO	0.729		
lb/ft3	88.39	SATURATION %	28.527		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value

PERMEABILITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Base kPa
137.8	62.0	0.0		62.01	6802.661	75.8	137.8

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	INFLOW Vc cc	INFLOW aVc cc	OUTFLOW Vc cc	OUTFLOW aVc cc	DAILY PERMEABILITY RESULTS INFLOW cm/s	DAILY PERMEABILITY RESULTS OUTFLOW cm/s
87-04-14	13:44	0	0	47.20	0.0	19.00	0.0		
87-04-14	13:53	9.0	540.0	47.80	0.60	18.20	0.80	3.01E-07	4.01E-07
87-04-14	14:22	38.0	2280.0	49.40	2.20	16.80	2.20	2.49E-07	2.18E-07
87-04-14	15:08	84.0	5040.0	51.40	4.20	14.60	4.40	1.96E-07	2.16E-07
87-04-14	15:51	127.0	7620.0	53.20	6.00	12.80	6.20	1.89E-07	1.89E-07
87-04-14	16:30	166.0	9960.0	54.60	7.40	11.40	7.60	1.62E-07	1.62E-07

COEFFICIENT of PERMEABILITY,k, cm/s

TOTAL FLOW

MINUTES		
166	INFLOW,k	2.19E-07
	OUTFLOW,k	2.37E-07
	AVERAGE,k	2.28E-07

NOTES

PART 1

MINUTES			
82	INFLOW,k	1.76E-07	cm/s
	OUTFLOW,k	1.76E-07	cm/s
	AVERAGE,k	1.76E-07	cm/s

PART 2

MINUTES			
157	INFLOW,k	1.95E-07	cm/s
	OUTFLOW,k	1.95E-07	cm/s
	AVERAGE,k	1.95E-07	cm/s
AVERAGE,k USE FOR ANALYSES		1.95E-07	cm/s

Data by F.A.R.

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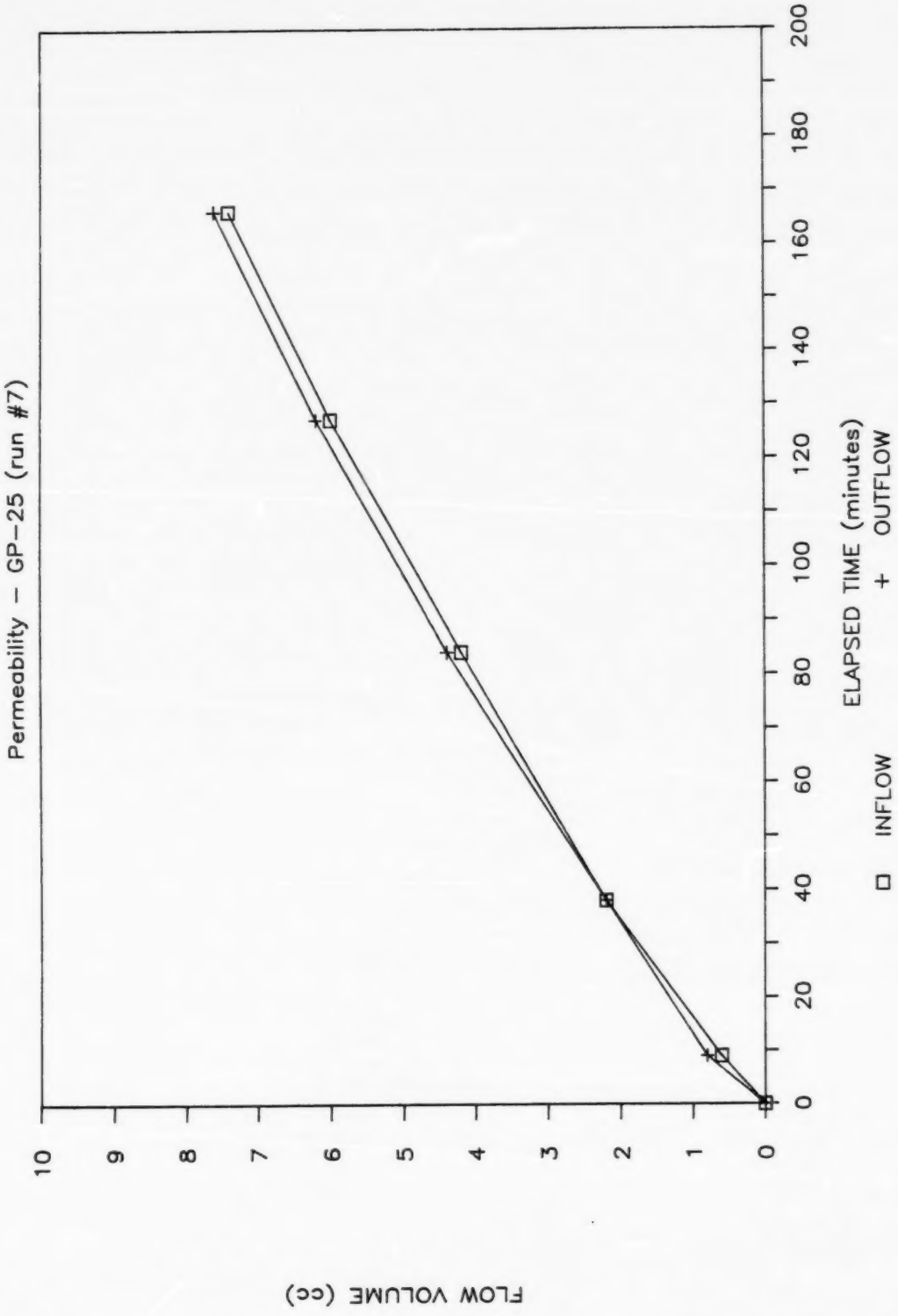
TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST
SHEET 2 OF 2

FIGURE 3-2



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TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 1 OF 2

FIGURE 4-1

BOREHOLE NUMBER — PROJECT 871-1159
SAMPLE NUMBER SP-25 (run #8)
SAMPLE LOCATION — Ontario Research Foundation /Tailings /Ontario
SAMPLE TYPE Cemented Tailings

ORIGINAL:	LENGTH cm	1.840	TESTED:	AREA cm2	10.75	WET WEIGHT gm	28.7
	DIAMETER cm	3.700		LENGTH cm	1.84	DRY WEIGHT gm	26.3
	AREA cm2	10.753		PRESSURE kPA	75.79	VOLUME WATER cc	2.4
	VOLUME cc	19.786		HYDRAULIC GRADIENT (p/l)	343.85		

WATER CONTENT initial %	2.40	SPECIFIC GRAVITY	2.300	POROSITY (initial) Vv/Vo %	42.16%
WATER CONTENT final %	16.40	VOLUME SOLIDS cc	11.443		
UNIT WEIGHT kN/m3	14.22	VOLUME VOIDS cc	8.343		
DRY UNIT WEIGHT kN/m3	13.89	VOID RATIO	0.729		
lb/ft3	88.39	SATURATION %	28.527		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value

PERMEABILITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Effective Confining Pressure Base kPa
137.8	62.0	0.0		62.01	6882.661	75.8	137.8

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	INFLOW Vc cc	INFLOW aVc cc	OUTFLOW Vc cc	OUTFLOW aVc cc	DAILY PERMEABILITY RESULTS INFLOW cm/s	DAILY PERMEABILITY RESULTS OUTFLOW cm/s
87-04-15	11:55	0	0	74.50	0.0	21.10	0.0		
87-04-15	13:29	94	5640	75.50	1.00	20.20	0.90	4.88E-08	4.32E-08
87-04-15	15:00	185	11100	76.20	1.70	19.30	1.80	3.47E-08	4.46E-08
87-04-15	15:47	232	13920	76.60	2.10	18.80	2.30	3.84E-08	4.80E-08
87-04-15	16:25	270	16200	76.90	2.40	18.50	2.63	3.56E-08	3.56E-08
87-04-15	16:43	288	17280	77.00	2.50	18.30	2.80	2.50E-08	5.01E-08
87-04-16	08:33	1238	74280	69.50	10.00	11.10	10.00	3.56E-08	3.42E-08

COEFFICIENT of PERMEABILITY,k, cm/s

TOTAL FLOW

MINUTES		
1238	INFLOW,k	3.62E-08
	OUTFLOW,k	4.26E-08
	AVERAGE,k	3.94E-08

NOTES

PART 1

MINUTES			
950	INFLOW,k	3.56E-08	cm/s
	OUTFLOW,k	3.42E-08	cm/s
	AVERAGE,k	3.49E-08	cm/s

PART 2

MINUTES			
1144	INFLOW,k	3.55E-08	cm/s
	OUTFLOW,k	3.59E-08	cm/s
	AVERAGE,k	3.57E-08	cm/s
AVERAGE,k USE FOR ANALYSES		3.57E-08	cm/s

Data by F.A.R.

Golder Associates

TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST
SHEET 2 OF 2

FIGURE 4-2

Golder Associates

TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 1 OF 2

FIGURE 5-1

BOREHOLE NUMBER — PROJECT 871-1159
SAMPLE NUMBER GP-25 (run #9)
SAMPLE LOCATION — Ontario Research Foundation /Tailings /Ontario
SAMPLE TYPE Cemented Tailings

ORIGINAL: LENGTH cm	1.840	TESTED: AREA cm2	10.75	WET WEIGHT gm	28.7
DIAMETER cm	3.700	LENGTH cm	1.84	DRY WEIGHT gm	26.3
AREA cm2	10.753	PRESSURE kPA	75.79	VOLUME WATER cc	2.4
VOLUME cc	19.786	HYDRAULIC GRADIENT (p/l)	343.85		

WATER CONTENT initial %	2.40	SPECIFIC GRAVITY	2.300	POROSITY (initial) Vv/Vo %	42.16%
WATER CONTENT final %	16.40	VOLUME SOLIDS cc	11.443		
UNIT WEIGHT kN/m3	14.22	VOLUME VOIDS cc	8.343		
DRY UNIT WEIGHT kN/m3	13.89	VOID RATIO	0.729		
lb/ft3	88.39	SATURATION %	28.527		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value

PERMEABILITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Effective Confining Pressure Base kPa
137.8	62.0	0.0		62.01	6802.661	75.8	137.8

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	INFLOW Vc cc	INFLOW aVc cc	OUTFLOW Vc cc	OUTFLOW aVc cc	DAILY PERMEABILITY RESULTS INFLOW cm/s	DAILY PERMEABILITY RESULTS OUTFLOW cm/s
87-04-20	08:55	0	0	62.40	0.0	22.30	0.0		
87-04-20	09:27	32	1920	62.00	0.40	23.00	0.30	5.64E-08	4.23E-08
87-04-20	10:03	68	4080	61.80	0.60	22.70	0.60	2.50E-08	3.76E-08
87-04-20	10:35	100	6000	61.60	0.80	22.50	0.80	2.82E-08	2.82E-08
87-04-20	13:09	254	15240	60.60	1.80	21.30	2.00	2.93E-08	3.51E-08

COEFFICIENT of PERMEABILITY,k, cm/s

TOTAL FLOW

MINUTES		
254	INFLOW,k	3.47E-08
	OUTFLOW,k	3.58E-08
	AVERAGE,k	3.52E-08

NOTES

PART 1			
MINUTES	INFLOW,k	2.93E-08	cm/s
154	OUTFLOW,k	3.51E-08	cm/s
	AVERAGE,k	3.22E-08	cm/s
PART 2			
MINUTES	INFLOW,k	2.84E-08	cm/s
222	OUTFLOW,k	3.45E-08	cm/s
	AVERAGE,k	3.15E-08	cm/s
AVERAGE,k USE FOR ANALYSES		3.15E-08	cm/s

Data by F.A.R.

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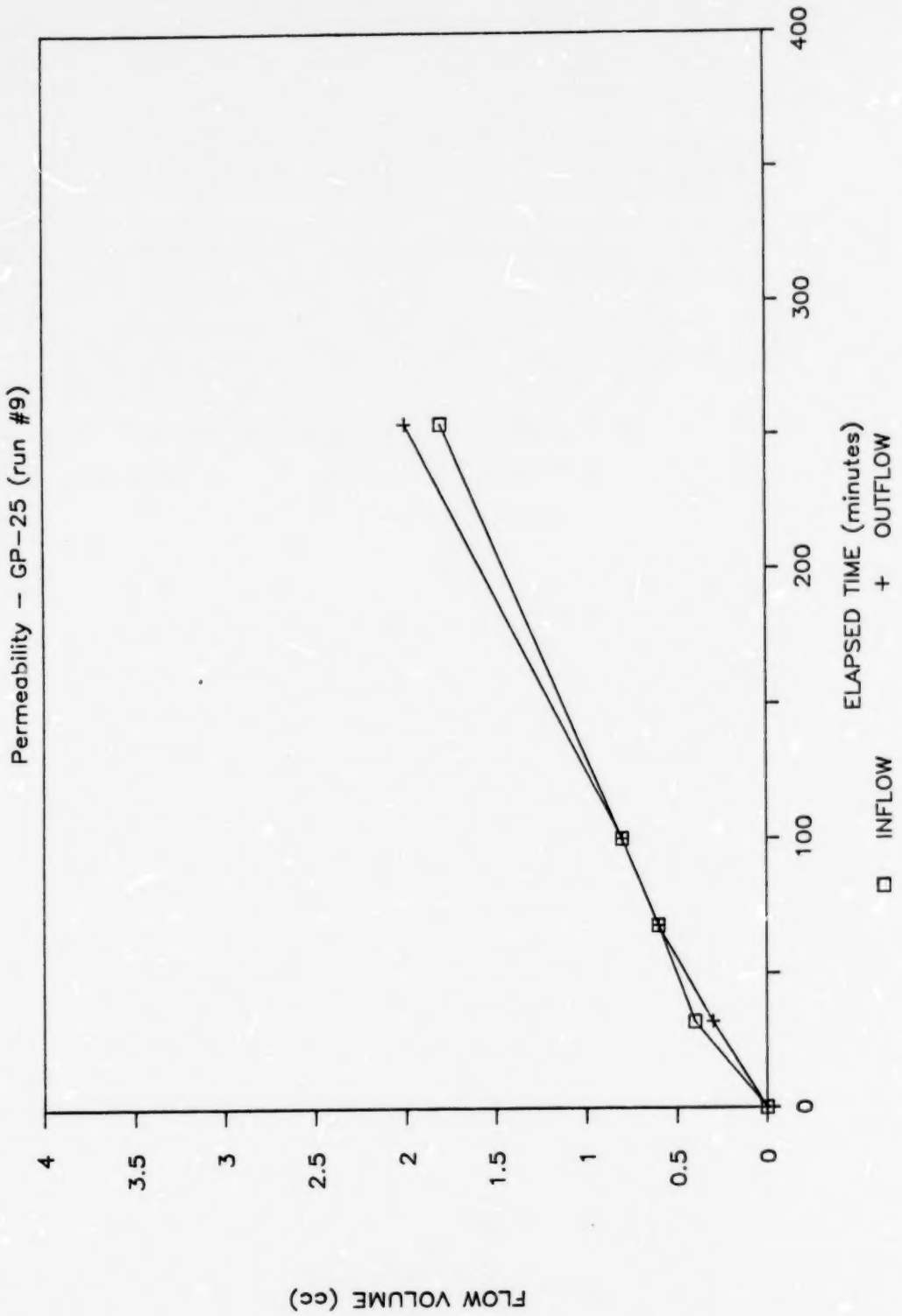
TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST
SHEET 2 OF 2

FIGURE 5-2



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TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 1 OF 2

FIGURE 6-1

BOREHOLE NUMBER — PROJECT 871-1159

SAMPLE NUMBER C-2 (run #1-#4 inclusive)

Sample Tested May 15 & 17,1987 — Ontario Research Foundation /Tailings /Ontario

SAMPLE TYPE Cemented Tailings

ORIGINAL:	LENGTH cm	2.970	TESTED:	AREA cm2	10.41	WET WEIGHT gm	55.0
	DIAMETER cm	3.640		LENGTH cm	2.97	DRY WEIGHT gm	52.4
	AREA cm2	10.408		PRESSURE kPA	21.22	VOLUME WATER cc	2.7
	VOLUME cc	30.910	HYDRAULIC GRADIENT (p/l)		123.56		

WATER CONTENT initial %	5.10	SPECIFIC GRAVITY	1.960	POROSITY (initial) Vv/Vo %	13.58%
WATER CONTENT final %	12.00	VOLUME SOLIDS cc	26.714		
UNIT WEIGHT kN/m3	17.46	VOLUME VOIDS cc	4.196		
DRY UNIT WEIGHT kN/m3	16.61	VOID RATIO	0.157		
lb/ft3	105.74	SATURATION %	64.106		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value

PERMEABILITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Effective Confining Pressure Base kPa
57.2	36.0	0.0		35.97	3819.309	21.2	57.2

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	INFLOW Vc cc	INFLOW aVc cc	OUTFLOW Vc cc	OUTFLOW aVc cc	DAILY PERMEABILITY RESULTS INFLOW cm/s	DAILY PERMEABILITY RESULTS OUTFLOW cm/s
87-05-15	09:36	0	0	59.80	0.0	25.80	0.0		
87-05-15	10:03	27.0	1620.0	89.00	29.20	0.00	25.00	1.40E-05	1.20E-05
87-05-15	10:03	0.0	0.0	89.20	0.00	24.50	0.00		
87-05-15	10:13	10.0	600.0	77.40	11.80	12.20	12.30	1.53E-05	1.59E-05
87-05-15	10:31	0.0	0.0	62.40	0.00	25.00	0.00		
87-05-15	11:05	34.0	2040.0	49.70	12.70	1.00	24.00	4.84E-06	9.15E-06
87-05-17	07:56	0.0	0.0	62.20	0.00	24.10	0.00		
87-05-17	09:30	94.0	5640.0	41.50	20.70	3.40	20.70	2.85E-06	2.85E-06

COEFFICIENT of PERMEABILITY,k, cm/s

TOTAL FLOW

MINUTES		
165	INFLOW,k	3.70E-05
	OUTFLOW,k	3.99E-05
	AVERAGE,k	3.85E-05

NOTES

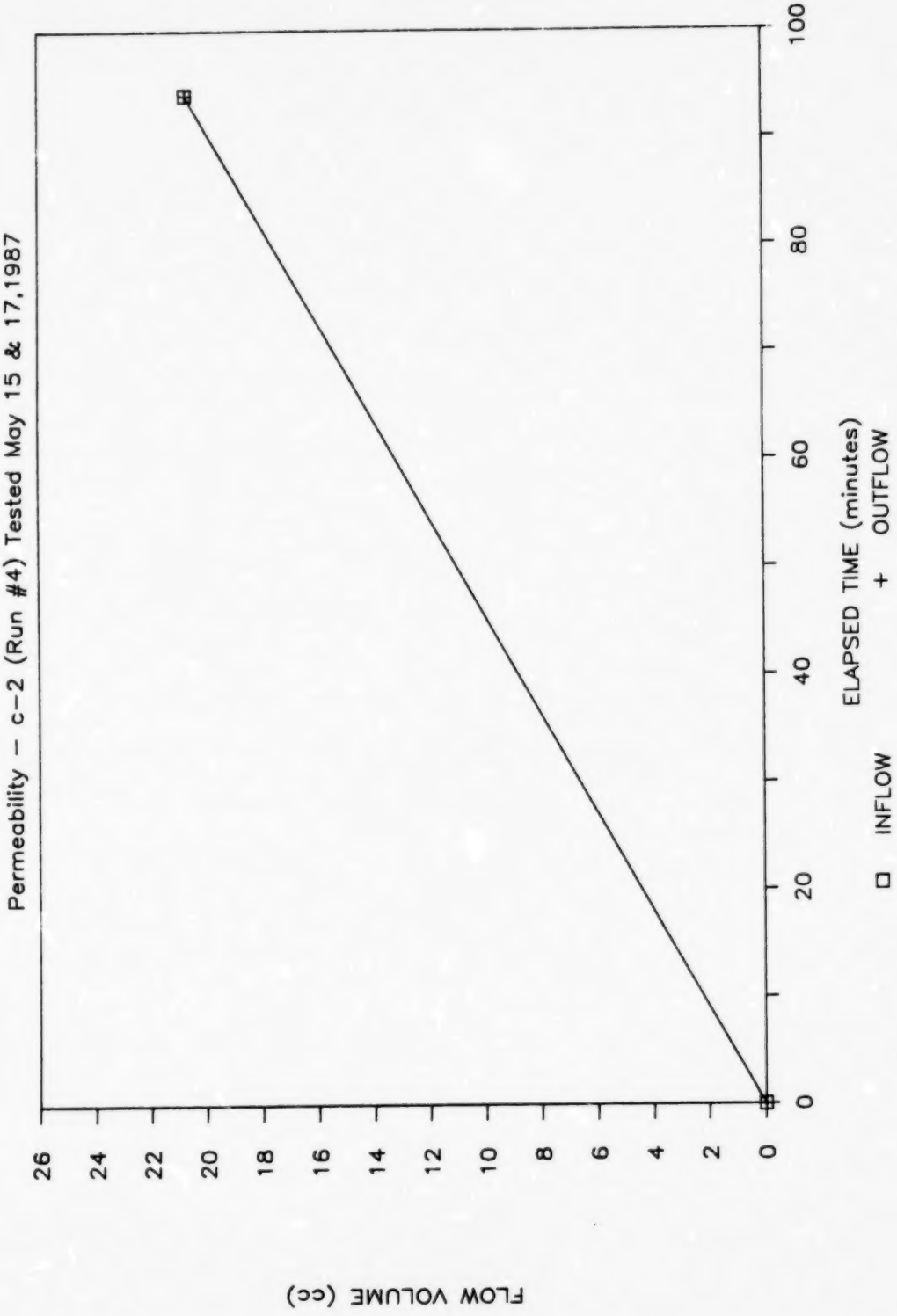
Data by F.A.R.

PART 1			
MINUTES	INFLOW,k	1.40E-05	cm/s
94	OUTFLOW,k	1.20E-05	cm/s
	AVERAGE,k	1.30E-05	cm/s
PART 2			
MINUTES	INFLOW,k	2.85E-06	cm/s
94	OUTFLOW,k	2.85E-06	cm/s
	AVERAGE,k	2.85E-06	cm/s
AVERAGE,k USE FOR ANALYSES		2.85E-06	cm/s

TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 2 OF 2

FIGURE 6-2



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TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 1 OF 2

FIGURE 7-1

BOREHOLE NUMBER — PROJECT 871-1159

SAMPLE NUMBER C-2 (run #1-#4 inclusive)

Sample Tested May 25 & 26,1987 — Ontario Research Foundation /Tailings /Ontario

SAMPLE TYPE Cemented Tailings

ORIGINAL:	LENGTH cm	2.460	TESTED:	AREA cm2	11.64	WET WEIGHT gm	49.1
	DIAMETER cm	3.850		LENGTH cm	2.46	DRY WEIGHT gm	46.3
	AREA cm2	11.643		PRESSURE kPA	50.99	VOLUME WATER cc	2.8
	VOLUME cc	28.642	HYDRAULIC GRADIENT (p/l)		74.38		

WATER CONTENT initial %	6.18	SPECIFIC GRAVITY	1.960	POROSITY (initial) Vv/Vo %	17.58%
WATER CONTENT final %	11.50	VOLUME SOLIDS cc	23.607		
UNIT WEIGHT kN/m3	16.80	VOLUME VOIDS cc	5.035		
DRY UNIT WEIGHT kN/m3	15.84	VOID RATIO	0.213		
lb/ft3	100.80	SATURATION %	56.810		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value

PERMEABILITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Base kPa
68.9	17.9	0.0		17.91	2128.867	51.0	68.9

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	INFLOW Vc cc	INFLOW aVc cc	OUTFLOW Vc cc	OUTFLOW aVc cc	DAILY PERMEABILITY RESULTS INFLOW cm/s	OUTFLOW cm/s
87-05-25	13:56	0	0	41.20	0.0	23.70	0.0		
87-05-25	17:14	198.0	11880.0	34.50	6.70	2.50	21.20	6.52E-07	2.06E-06
87-05-25	17:14	0.0	0.0	34.50	0.00	25.00	0.00		
87-05-25	18:23	69.0	4140.0	32.50	2.00	17.00	9.00	5.58E-07	2.23E-06
87-05-26	08:48	0.0	0.0	51.60	0.00	25.00	0.00		
87-05-26	10:40	112.0	6720.0	43.00	8.60	10.90	14.10	1.48E-06	2.43E-06

COEFFICIENT of PERMEABILITY,k, cm/s

TOTAL FLOW

MINUTES		
379	INFLOW,k	2.69E-06
	OUTFLOW,k	6.72E-06
	AVERAGE,k	4.71E-06

NOTES

PART 1

MINUTES			
112	INFLOW,k	1.48E-06	cm/s
	OUTFLOW,k	2.43E-06	cm/s
	AVERAGE,k	1.95E-06	cm/s

PART 2

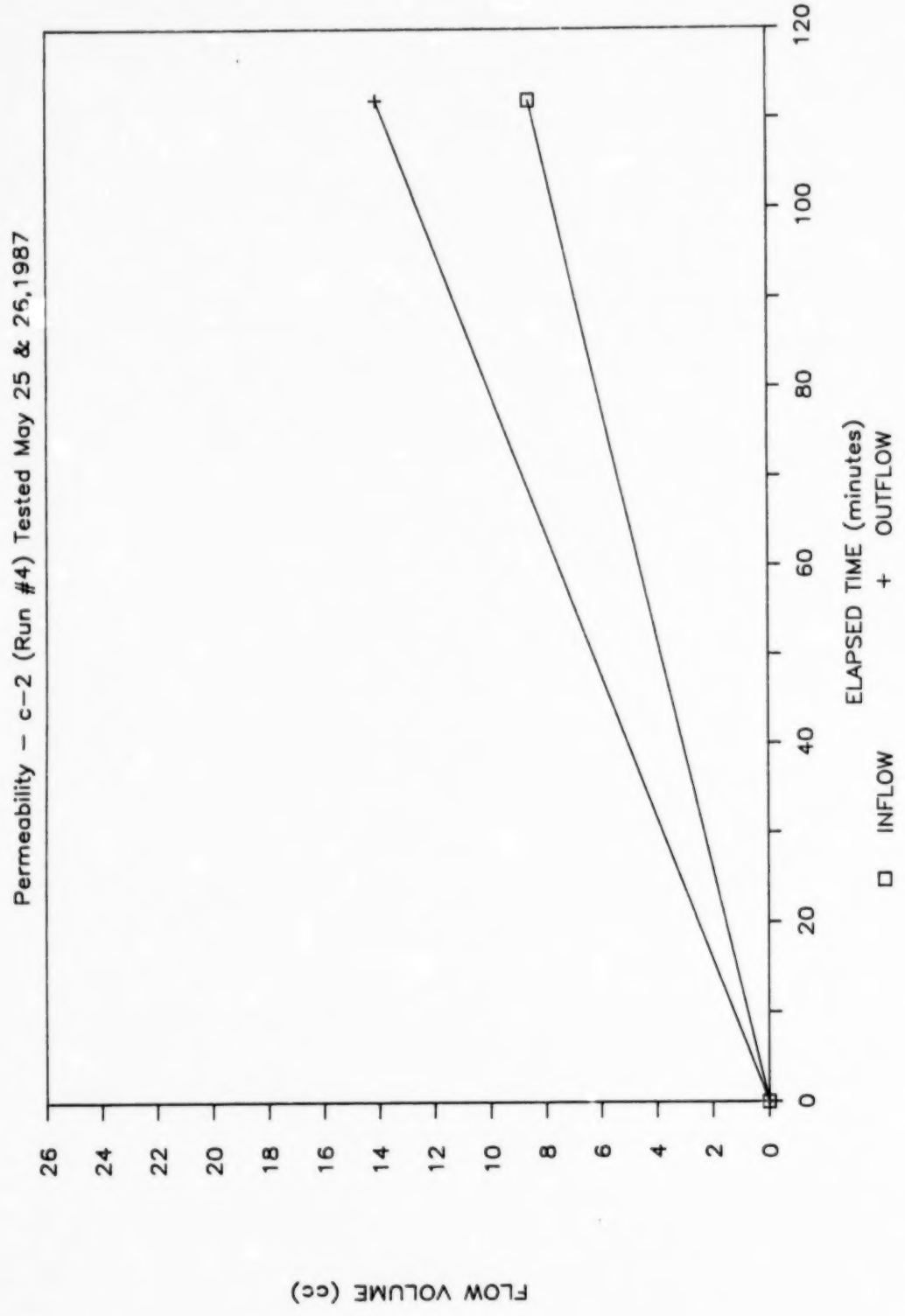
MINUTES			
112	INFLOW,k	1.48E-06	cm/s
	OUTFLOW,k	2.43E-06	cm/s
	AVERAGE,k	1.95E-06	cm/s
AVERAGE,k USE FOR ANALYSES		1.95E-06	cm/s

Data by F.A.R.

Golder Associates

TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST
SHEET 2 OF 2

FIGURE 7-2



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TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 1 OF 2

FIGURE 8-1

BOREHOLE NUMBER — PROJECT 871-1159

SAMPLE NUMBER KL-5 (run #1-#4 inclusive)

Sample Tested May 15 & 17,1987 — Ontario Research Foundation /Tailings /Ontario

SAMPLE TYPE Cemented Tailings

ORIGINAL: LENGTH cm	3.275	TESTED: AREA cm2	10.64	WET WEIGHT gm	54.5
DIAMETER cm	3.680	LENGTH cm	3.27	DRY WEIGHT gm	49.1
AREA cm2	10.638	PRESSURE kPA	25.84	VOLUME WATER cc	5.3
VOLUME cc	34.838	HYDRAULIC GRADIENT (p/l)	95.52		

WATER CONTENT initial %	18.48	SPECIFIC GRAVITY	2.280	POROSITY (initial) Vv/Vo %	38.16%
WATER CONTENT final %	27.80	VOLUME SOLIDS cc	21.544		
UNIT WEIGHT kN/m3	15.32	VOLUME VOIDS cc	13.294		
DRY UNIT WEIGHT kN/m3	13.88	VOID RATIO	0.617		
lb/ft3	88.36	SATURATION %	48.168		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value

PERMEABILITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Effective Confining Pressure Base kPa
56.5	30.7	0.0		30.66	3327.875	25.8	56.5

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	INFLOW Vc cc	INFLOW aVc cc	OUTFLOW Vc cc	OUTFLOW aVc cc	DAILY PERMEABILITY RESULTS INFLOW cm/s	DAILY PERMEABILITY RESULTS OUTFLOW cm/s
87-05-15	10:44	0	0	27.80	0.0	11.50	0.0		
87-05-15	11:38	54.0	3240.0	42.80	15.00	1.50	10.00	4.56E-06	3.04E-06
87-05-15	11:51	0.0	0.0	45.40	3.00	24.20	0.00		
87-05-15	14:13	142.0	8520.0	69.40	24.00	0.20	24.00	2.77E-06	2.77E-06
87-05-17	07:59	0.0	0.0	51.00	0.00	24.20	0.00		
87-05-17	09:55	116.0	6960.0	29.00	22.00	1.80	22.50	3.11E-06	3.18E-06
87-05-17	09:56	0.0	0.0	29.00	0.00	24.60	0.00		
87-05-17	12:17	141.0	8460.0	51.80	22.80	1.50	23.10	2.65E-06	2.69E-06

COEFFICIENT of PERMEABILITY,k, cm/s

TOTAL FLOW

MINUTES		
453	INFLOW,k	1.31E-05
	OUTFLOW,k	1.17E-05
	AVERAGE,k	1.24E-05

NOTES

PART 1

MINUTES			
141	INFLOW,k	4.56E-06	cm/s
	OUTFLOW,k	3.04E-06	cm/s
	AVERAGE,k	3.80E-06	cm/s

PART 2

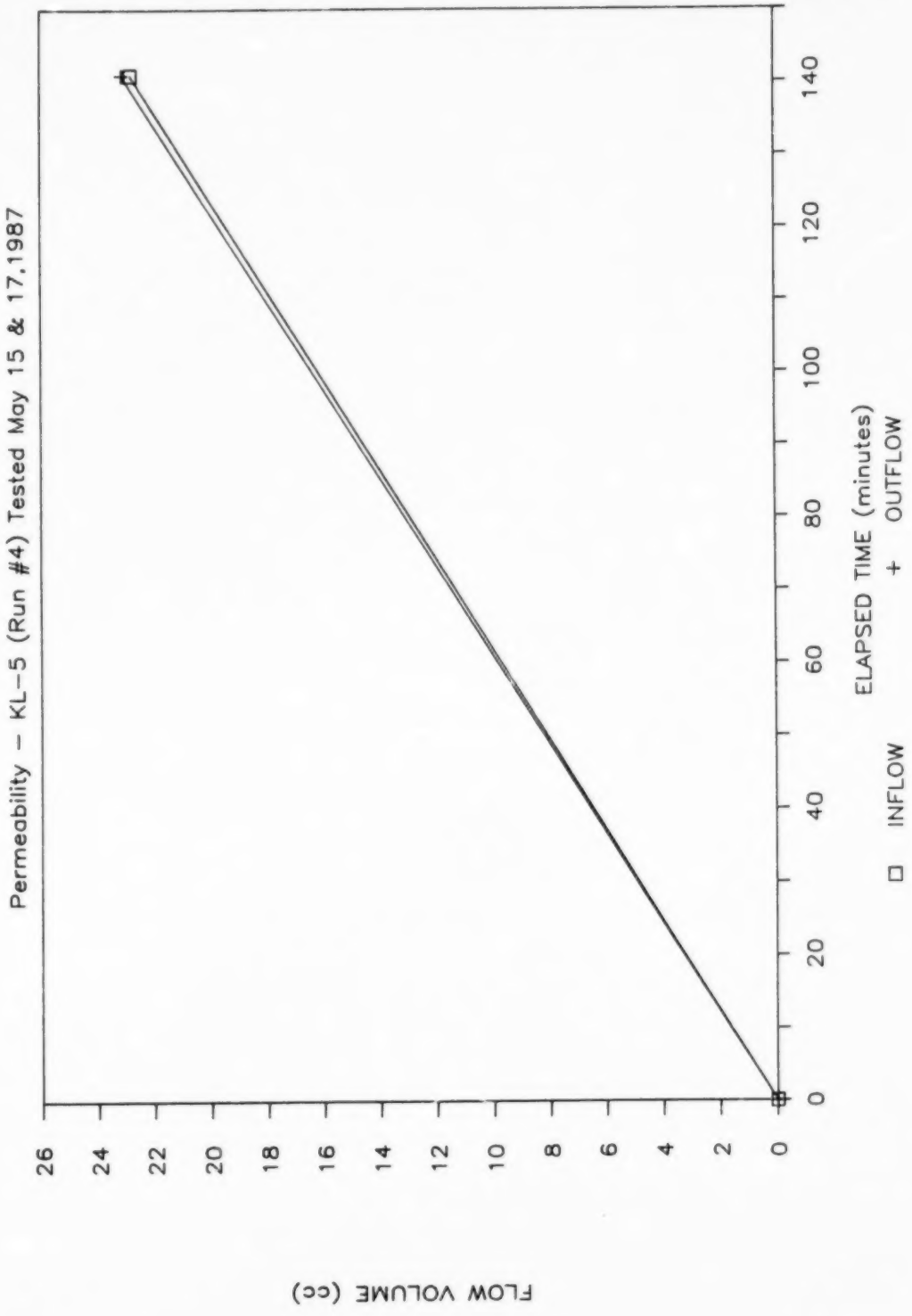
MINUTES			
141	INFLOW,k	2.65E-06	cm/s
	OUTFLOW,k	2.69E-06	cm/s
	AVERAGE,k	2.67E-06	cm/s
AVERAGE,k USE FOR ANALYSES		2.67E-06	cm/s

Data by F.A.R.

Golder Associates

TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST
SHEET 2 OF 2

FIGURE 8-2



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TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 1 OF 2

FIGURE 9-1

BOREHOLE NUMBER — PROJECT 871-1159

SAMPLE NUMBER KL-5 (run 01-04 inclusive)
Sample Tested May 22 & 25,1987 — Ontario Research Foundation /Tailings /Ontario

SAMPLE TYPE Cemented Tailings

ORIGINAL: LENGTH cm	3.010	TESTED: AREA cm2	9.68	WET WEIGHT gm	47.9
DIAMETER cm	3.510	LENGTH cm	3.01	DRY WEIGHT gm	42.5
AREA cm2	9.677	PRESSURE kPA	50.71	VOLUME WATER cc	5.4
VOLUME cc	29.129	HYDRAULIC GRADIENT (p/l)	61.66		

WATER CONTENT initial %	11.30	SPECIFIC GRAVITY	2.280	POROSITY (initial) Vv/Vo %	36.01%
WATER CONTENT final %	27.20	VOLUME SOLIDS cc	18.640		
UNIT WEIGHT kN/m3	16.12	VOLUME VOIDS cc	10.489		
DRY UNIT WEIGHT kN/m3	14.48	VOID RATIO	0.563		
lb/ft3	92.19	SATURATION %	51.484		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value

PERMEABILITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Effective Confining Pressure Base kPa
68.9	18.2	0.0		18.19	1795.939	50.7	68.9

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	INFLOW Vc cc	INFLOW aVc cc	OUTFLOW Vc cc	OUTFLOW aVc cc	DAILY PERMEABILITY RESULTS INFLOW cm/s	DAILY PERMEABILITY RESULTS OUTFLOW cm/s
87-05-22	08:51	0	0	10.00	0.0	19.90	0.0		
87-05-22	10:58	127.0	7620.0	25.20	15.20	12.20	7.70	3.34E-06	1.69E-06
87-05-22	15:12	0.0	0.0	42.40	0.00	23.30	0.00		
87-05-22	16:57	105.0	6300.0	46.50	4.10	19.10	4.20	1.09E-06	1.12E-06
87-05-25	08:47	0.0	0.0	46.60	0.00	19.10	0.00		
87-05-25	10:27	100.0	6000.0	64.00	17.40	1.60	17.50	4.86E-06	4.89E-06
87-05-25	10:30	0.0	0.0	64.20	0.00	24.30	0.00		
87-05-25	13:00	150.0	9480.0	85.50	21.30	3.60	20.70	3.77E-06	3.66E-06

COEFFICIENT of PERMEABILITY,k, cm/s

TOTAL FLOW

MINUTES		
498	INFLOW,k	1.31E-05
	OUTFLOW,k	1.14E-05
	AVERAGE,k	1.22E-05

NOTES

PART 1

MINUTES			
158	INFLOW,k	3.34E-06	cm/s
	OUTFLOW,k	1.69E-06	cm/s
	AVERAGE,k	2.52E-06	cm/s

PART 2

MINUTES			
158	INFLOW,k	3.77E-06	cm/s
	OUTFLOW,k	3.66E-06	cm/s
	AVERAGE,k	3.71E-06	cm/s
AVERAGE,k USE FOR ANALYSES		3.71E-06	cm/s

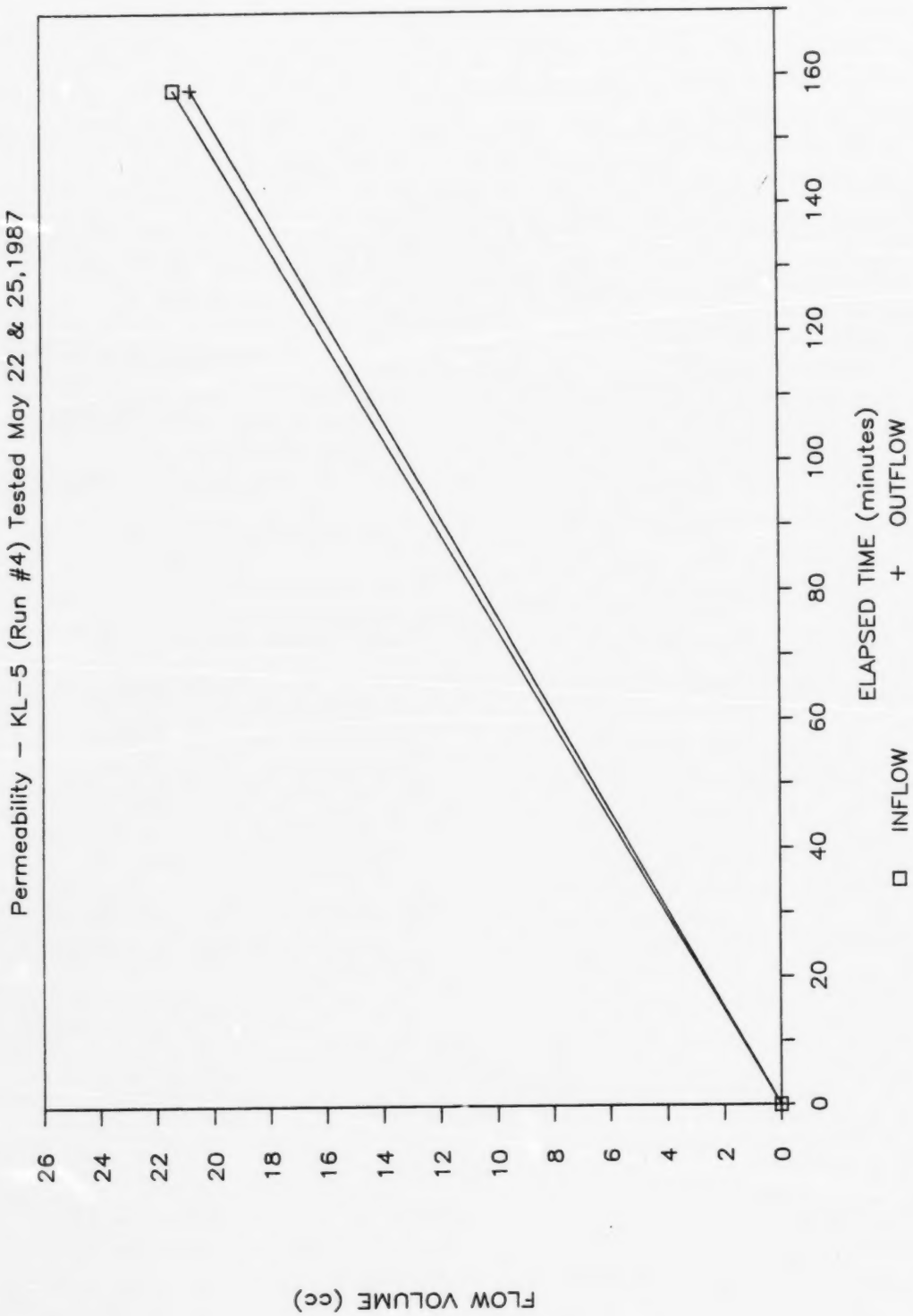
Data by F.A.R.

Golder Associates

TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 2 OF 2

FIGURE 9-2



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TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 1 OF 2

FIGURE 10-1

BOREHOLE NUMBER — PROJECT 871-1159

SAMPLE NUMBER KK-1 (run #1-#4 inclusive)
Sample Tested May 28,1987 — Ontario Research Foundation /Tailings /Ontario

SAMPLE TYPE Cemented Tailings

ORIGINAL: LENGTH cm	2.150	TESTED: AREA cm2	10.81	WET WEIGHT gm	44.7
DIAMETER cm	3.710	LENGTH cm	2.15	DRY WEIGHT gm	41.0
AREA cm2	10.812	PRESSURE kPA	54.22	VOLUME WATER cc	3.7
VOLUME cc	23.245	HYDRAULIC GRADIENT (p/l)	69.64		

WATER CONTENT initial %	9.00	SPECIFIC GRAVITY	2.490	POROSITY (initial) Vv/Vo %	29.16%
WATER CONTENT final %	17.80	VOLUME SOLIDS cc	16.466		
UNIT WEIGHT kN/m3	18.95	VOLUME VOIDS cc	6.779		
DRY UNIT WEIGHT kN/m3	17.29	VOID RATIO	0.412		
lb/ft3	110.06	SATURATION %	54.430		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value

PERMEABILITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Base kPa
68.9	14.7	0.0		14.68	1618.947	54.2	68.9

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	INFLOW Vc cc	INFLOW aVc cc	OUTFLOW Vc cc	OUTFLOW aVc cc	DAILY PERMEABILITY RESULTS INFLOW cm/s	DAILY PERMEABILITY RESULTS OUTFLOW cm/s
87-05-20	09:45	0	0	7.20	0.0	24.80	0.0		
87-05-20	09:47	2.0	120.0	23.20	16.00	10.50	14.30	1.77E-04	1.58E-04
87-05-20	09:54	0.0	0.0	43.00	0.00	23.70	0.00		
87-05-20	09:58	4.0	240.0	66.00	23.00	0.70	23.00	1.27E-04	1.27E-04
87-05-20	10:03	0.0	0.0	66.80	0.00	22.80	0.00		
87-05-20	10:08	5.0	300.0	88.00	21.20	1.40	20.60	9.38E-05	9.12E-05
87-05-20	10:42	0.0	0.0	88.80	0.00	22.60	0.00		
87-05-20	10:46	4.0	240.0	65.70	23.10	0.00	22.60	1.28E-04	1.25E-04

COEFFICIENT of PERMEABILITY,k, cm/s

TOTAL FLOW

MINUTES		
15	INFLOW,k	5.26E-04
	OUTFLOW,k	5.02E-04
	AVERAGE,k	5.14E-04

NOTES

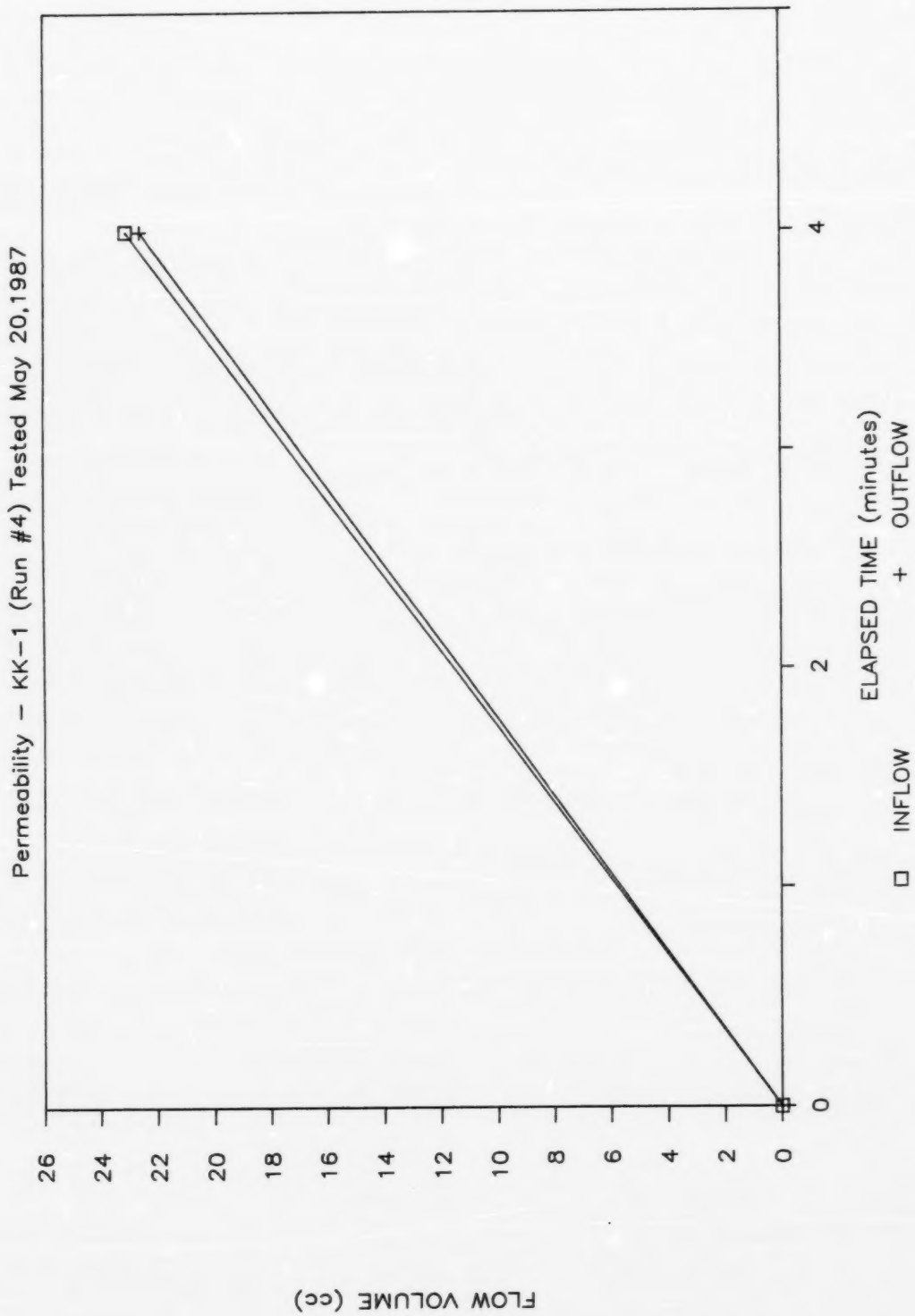
PART 1			
MINUTES	INFLOW,k	1.77E-04	cm/s
4	OUTFLOW,k	1.58E-04	cm/s
	AVERAGE,k	1.68E-04	cm/s
PART 2			
MINUTES	INFLOW,k	1.28E-04	cm/s
4	OUTFLOW,k	1.25E-04	cm/s
	AVERAGE,k	1.26E-04	cm/s
AVERAGE,k USE FOR ANALYSES		1.26E-04	cm/s

Data by F.A.R.

TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 2 OF 2

FIGURE 10-2



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TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 1 OF 2

FIGURE 11-1

BOREHOLE NUMBER — PROJECT 871-1159

SAMPLE NUMBER KK-1 (run #5-#8 inclusive)

Sample Tested May 20 & 21,1987 — Ontario Research Foundation /Tailings /Ontario

SAMPLE TYPE Cemented Tailings

ORIGINAL:	LENGTH cm	2.150	TESTED:	AREA cm2	10.81	WET WEIGHT gm	44.7
	DIAMETER cm	3.710		LENGTH cm	2.15	DRY WEIGHT gm	41.0
	AREA cm2	10.812		PRESSURE kPA	54.22	VOLUME WATER cc	3.7
	VOLUME cc	23.245	HYDRAULIC GRADIENT (p/l)		69.64		

WATER CONTENT initial %	9.00	SPECIFIC GRAVITY	2.498	POROSITY (initial) Vv/Vo %	29.16%
WATER CONTENT final %	17.80	VOLUME SOLIDS cc	16.466		
UNIT WEIGHT kN/m3	18.85	VOLUME VOIDS cc	6.779		
DRY UNIT WEIGHT kN/m3	17.29	VOID RATIO	0.412		
lb/ft3	110.06	SATURATION %	54.430		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value

PERMEABILITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Effective Confining Pressure Base kPa
68.9	14.7	0.0		14.68	1618.947	54.2	68.9

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	INFLOW Vc cc	INFLOW aVc cc	OUTFLOW Vc cc	OUTFLOW aVc cc	DAILY PERMEABILITY RESULTS INFLOW cm/s	DAILY PERMEABILITY RESULTS OUTFLOW cm/s
87-05-20	13:03	0	0	32.60	0.0	23.20	0.0		
87-05-20	14:09	66.0	3960.0	12.20	20.40	2.70	20.50	6.84E-06	6.87E-06
87-05-20	14:43	0.0	0.0	2.80	0.00	13.50	0.00		
87-05-20	15:18	35.0	2100.0	16.40	13.60	0.00	13.50	8.60E-06	8.54E-06
87-05-21	09:52	0.0	0.0	19.40	0.00	21.00	0.00		
87-05-21	10:26	34.0	2040.0	40.40	21.00	0.00	21.00	1.37E-05	1.37E-05
87-05-21	10:34	0.0	0.0	41.00	0.00	23.70	0.00		
87-05-21	11:14	40.0	2400.0	61.60	20.60	3.10	20.60	1.14E-05	1.14E-05

COEFFICIENT of PERMEABILITY,k, cm/s

TOTAL FLOW

MINUTES		
175	INFLOW,k	4.05E-05
	OUTFLOW,k	4.05E-05
	AVERAGE,k	4.05E-05

NOTES

PART 1

MINUTES			
40	INFLOW,k	6.84E-06	cm/s
	OUTFLOW,k	6.87E-06	cm/s
	AVERAGE,k	6.86E-06	cm/s

PART 2

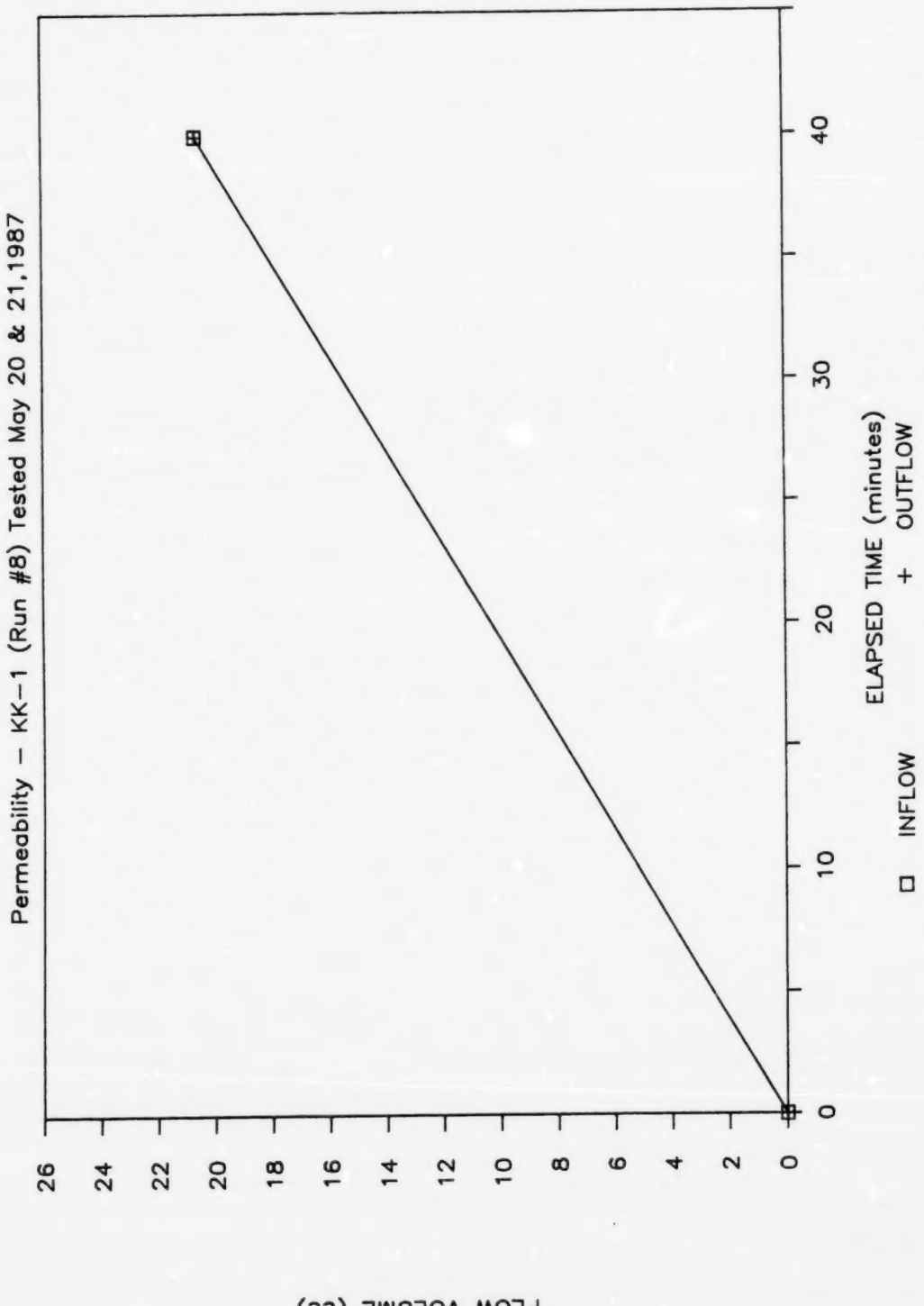
MINUTES			
40	INFLOW,k	1.14E-05	cm/s
	OUTFLOW,k	1.14E-05	cm/s
	AVERAGE,k	1.14E-05	cm/s
AVERAGE,k USE FOR ANALYSES		1.14E-05	cm/s

Data by F.A.R.

Golder Associates

TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST
SHEET 2 OF 2

FIGURE 11-2



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TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 1 OF 2

FIGURE 12-1

BOREHOLE NUMBER — PROJECT 871-1159

SAMPLE NUMBER KK-1 (run #1-#4 inclusive)
Sample Tested May 25,1987 — Ontario Research Foundation /Tailings /Ontario

SAMPLE TYPE Cemented Tailings

ORIGINAL:	LENGTH cm	2.210	TESTED:	AREA cm2	10.24	WET WEIGHT gm	42.7
	DIAMETER cm	3.610		LENGTH cm	2.21	DRY WEIGHT gm	39.8
	AREA cm2	10.237		PRESSURE kPA	50.30	VOLUME WATER cc	2.9
	VOLUME cc	22.623	HYDRAULIC GRADIENT (p/l)		85.88		

WATER CONTENT initial %	6.80	SPECIFIC GRAVITY	2.490	POROSITY (initial) Vv/Vo %	29.35%
WATER CONTENT final %	15.10	VOLUME SOLIDS cc	15.984		
UNIT WEIGHT kN/m3	18.51	VOLUME VOIDS cc	6.639		
DRY UNIT WEIGHT kN/m3	17.33	VOID RATIO	0.415		
lb/ft3	110.33	SATURATION %	43.981		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value

PERMEABILITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Base kPa
68.9	18.6	0.0		18.60	1943.048	50.3	68.9

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	INFLOW Vc cc	INFLOW aVc cc	OUTFLOW Vc cc	OUTFLOW aVc cc	DAILY PERMEABILITY RESULTS INFLOW cm/s	DAILY PERMEABILITY RESULTS OUTFLOW cm/s
87-05-25	09:20	0	0	86.00	0.0	14.30	0.0		
87-05-25	09:36	16.0	960.0	68.20	17.80	1.40	12.90	2.11E-05	1.53E-05
87-05-25	09:42	0.0	0.0	67.60	0.00	23.40	0.00		
87-05-25	10:11	29.0	1740.0	44.00	23.60	0.00	23.40	1.54E-05	1.53E-05
87-05-25	10:13	0.0	0.0	43.80	0.00	23.50	0.00		
87-05-25	10:45	32.0	1920.0	21.10	22.70	0.70	22.80	1.34E-05	1.35E-05
87-05-25	10:48	0.0	0.0	21.00	0.00	23.00	0.00		
87-05-25	11:17	29.0	1740.0	0.40	20.60	3.20	20.60	1.35E-05	1.35E-05

COEFFICIENT of PERMEABILITY,k, cm/s

TOTAL FLOW

MINUTES		
106	INFLOW,k	6.34E-05
	OUTFLOW,k	5.75E-05
	AVERAGE,k	6.05E-05

NOTES

PART 1

MINUTES			
29	INFLOW,k	2.11E-05	cm/s
	OUTFLOW,k	1.53E-05	cm/s
	AVERAGE,k	1.82E-05	cm/s

PART 2

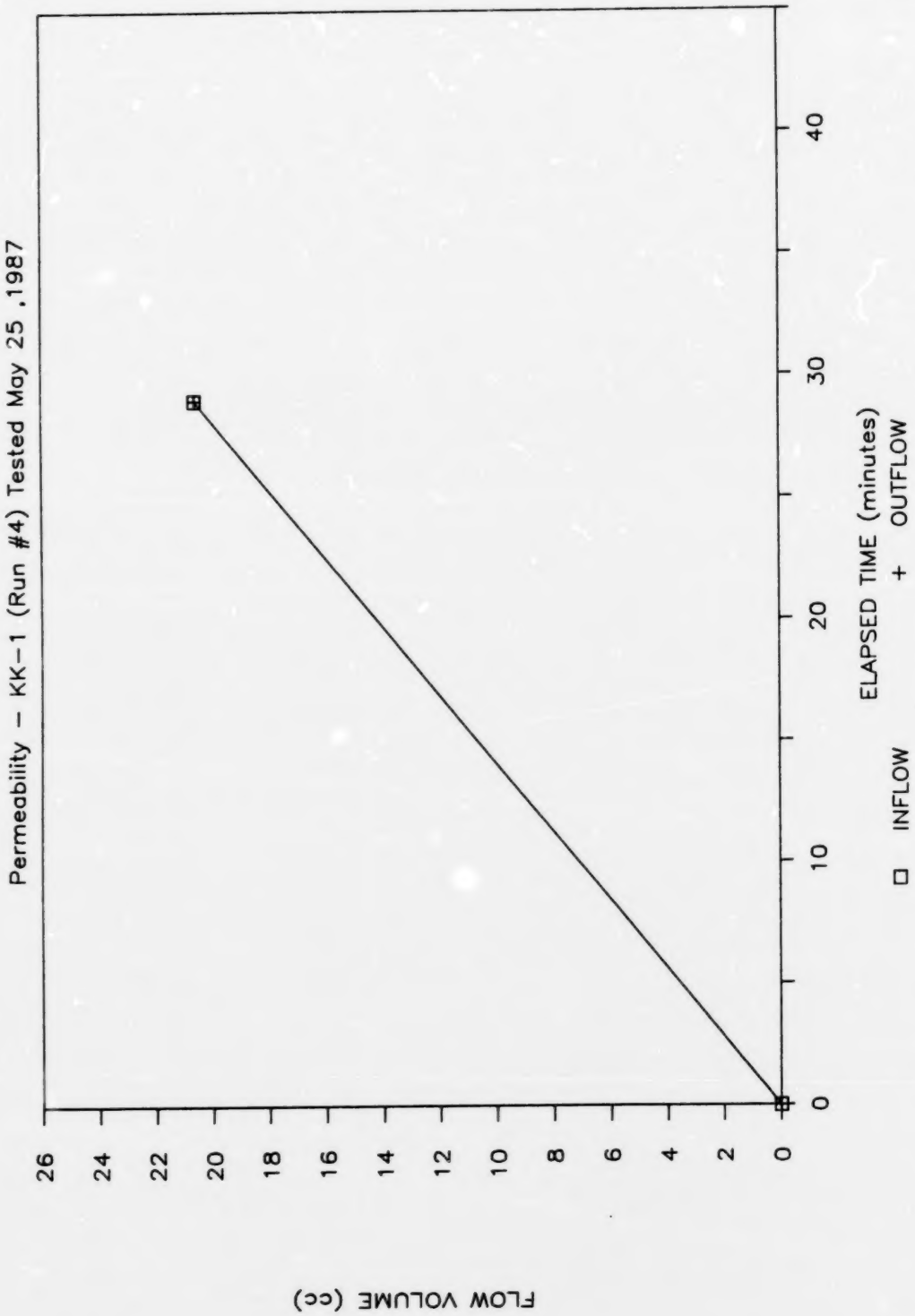
MINUTES			
29	INFLOW,k	1.35E-05	cm/s
	OUTFLOW,k	1.35E-05	cm/s
	AVERAGE,k	1.35E-05	cm/s
AVERAGE,k USE FOR ANALYSES		1.35E-05	cm/s

Data by F.A.R.

Golder Associates

TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST
SHEET 2 OF 2

FIGURE 12-2



Golder Associates

TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 1 OF 2

FIGURE 13-1

BOREHOLE NUMBER — PROJECT 871-1159

SAMPLE NUMBER KK-1 (run #5-#8 inclusive)
Sample Tested May 25,1987 — Ontario Research Foundation /Tailings /Ontario

SAMPLE TYPE Cemented Tailings

ORIGINAL:	LENGTH cm	2.210	TESTED:	AREA cm2	10.24	WET WEIGHT gm	42.7
	DIAMETER cm	3.610		LENGTH cm	2.21	DRY WEIGHT gm	39.8
	AREA cm2	10.237		PRESSURE kPA	50.30	VOLUME WATER cc	2.9
	VOLUME cc	22.623	HYDRAULIC GRADIENT (p/l)		85.88		

WATER CONTENT initial %	6.80	SPECIFIC GRAVITY	2.490	POROSITY (initial) Vv/Vo %	29.35%
WATER CONTENT final %	15.10	VOLUME SOLIDS cc	15.984		
UNIT WEIGHT kN/m3	18.51	VOLUME VOIDS cc	6.639		
DRY UNIT WEIGHT kN/m3	17.33	VOID RATIO	0.415		
lb/ft3	110.33	SATURATION %	43.981		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value

PERMEABILITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Base kPa
68.9	18.6	0.0		18.60	1943.048	50.3	68.9

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	INFLOW Vc cc	INFLOW aVc cc	OUTFLOW Vc cc	OUTFLOW aVc cc	DAILY PERMEABILITY RESULTS INFLOW cm/s	DAILY PERMEABILITY RESULTS OUTFLOW cm/s
87-05-25	11:22	0	0	0.40	0.0	25.30	0.0		
87-05-25	11:46	24.0	1440.0	24.60	24.20	1.10	24.20	1.91E-05	1.91E-05
87-05-25	11:50	0.0	0.0	24.90	0.00	23.90	0.00		
87-05-25	12:38	48.0	2880.0	34.00	9.10	14.80	9.10	3.59E-06	3.59E-06
87-05-25	13:07	0.0	0.0	61.20	0.00	24.10	0.00		
87-05-25	13:36	29.0	1740.0	82.40	21.20	3.20	20.90	1.39E-05	1.37E-05
87-05-25	13:53	0.0	0.0	83.60	0.00	23.80	0.00		
87-05-25	14:15	22.0	1320.0	61.30	22.30	1.70	22.10	1.92E-05	1.90E-05

COEFFICIENT of PERMEABILITY,k, cm/s

TOTAL FLOW

MINUTES		
123	INFLOW,k	5.58E-05
	OUTFLOW,k	5.54E-05
	AVERAGE,k	5.56E-05

NOTES

PART 1

MINUTES			
22	INFLOW,k	1.91E-05	cm/s
	OUTFLOW,k	1.91E-05	cm/s
	AVERAGE,k	1.91E-05	cm/s

PART 2

MINUTES			
22	INFLOW,k	1.92E-05	cm/s
	OUTFLOW,k	1.90E-05	cm/s
	AVERAGE,k	1.91E-05	cm/s
AVERAGE,k USE FOR ANALYSES		1.91E-05	cm/s

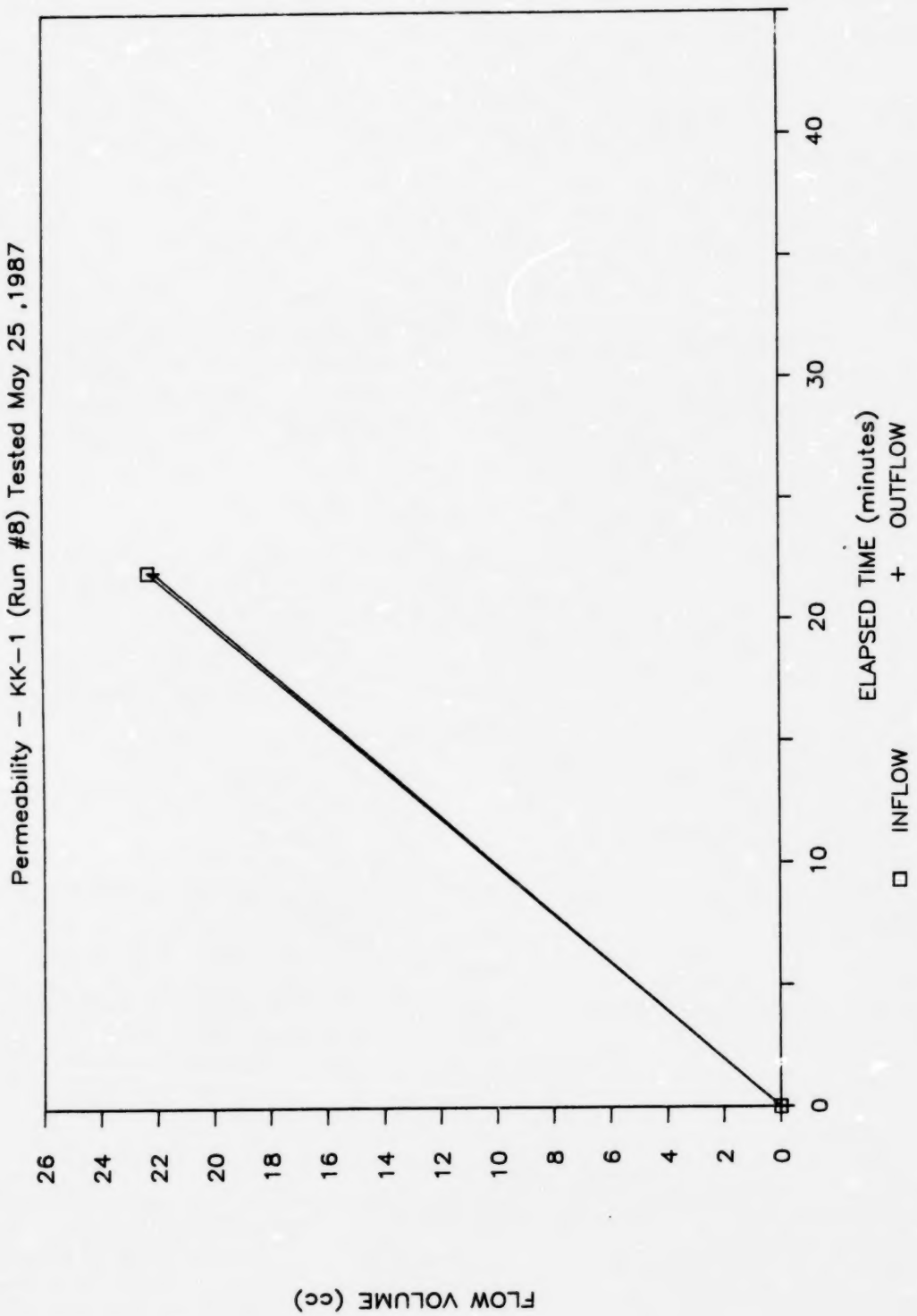
Data by F.A.R.

Golder Associates

TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 2 OF 2

FIGURE 13-2



Golder Associates

TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 1 OF 2

FIGURE 14-1

BOREHOLE NUMBER — PROJECT 871-1159

SAMPLE NUMBER MW-2 (run #1-#4 inclusive)

Sample Tested May 20,1987 — Ontario Research Foundation /Tailings /Ontario

SAMPLE TYPE Cemented Tailings

ORIGINAL:	LENGTH cm	2.010	TESTED:	AREA cm2	10.93	WET WEIGHT gm	44.1
	DIAMETER cm	3.730		LENGTH cm	2.01	DRY WEIGHT gm	42.8
	AREA cm2	10.929		PRESSURE kPA	54.22	VOLUME WATER cc	1.2
	VOLUME cc	21.966		HYDRAULIC GRADIENT (p/l)	74.50		

WATER CONTENT initial %	2.90	SPECIFIC GRAVITY	2.550	POROSITY (initial) Vv/Vo %	23.50%
WATER CONTENT final %	10.40	VOLUME SOLIDS cc	16.804		
UNIT WEIGHT kN/m3	19.68	VOLUME VOIDS cc	5.163		
DRY UNIT WEIGHT kN/m3	19.13	VOID RATIO	0.307		
lb/ft3	121.74	SATURATION %	24.213		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value

PERMEABILITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Base kPa
68.9	14.7	0.0		14.68	1636.616	54.2	68.9

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	INFLOW Vc cc	INFLOW aVc cc	OUTFLOW Vc cc	OUTFLOW aVc cc	DAILY PERMEABILITY RESULTS INFLOW cm/s	DAILY PERMEABILITY RESULTS OUTFLOW cm/s
87-05-20	09:45	0	0	7.20	0.0	24.00	0.0		
87-05-20	09:47	2.0	120.0	23.20	16.00	10.50	14.30	1.64E-04	1.46E-04
87-05-20	09:54	0.0	0.0	43.20	0.00	23.70	0.00		
87-05-20	09:58	4.0	240.0	66.00	23.00	0.70	23.00	1.18E-04	1.18E-04
87-05-20	10:03	0.0	0.0	66.80	0.00	22.00	0.00		
87-05-20	10:08	5.0	300.0	88.00	21.20	1.40	20.60	8.68E-05	8.43E-05
87-05-20	10:42	0.0	0.0	88.80	0.00	22.60	0.00		
87-05-20	10:46	4.0	240.0	65.70	23.10	0.00	22.60	1.18E-04	1.16E-04

COEFFICIENT of PERMEABILITY,k, cm/s

TOTAL FLOW

MINUTES		
15	INFLOW,k	4.86E-04
	OUTFLOW,k	4.64E-04
	AVERAGE,k	4.75E-04

PART 1			
MINUTES	INFLOW,k	1.64E-04	cm/s
4	OUTFLOW,k	1.46E-04	cm/s
	AVERAGE,k	1.55E-04	cm/s
PART 2			
MINUTES	INFLOW,k	1.18E-04	cm/s
4	OUTFLOW,k	1.16E-04	cm/s
	AVERAGE,k	1.17E-04	cm/s
AVERAGE,k USE FOR ANALYSES		1.17E-04	cm/s

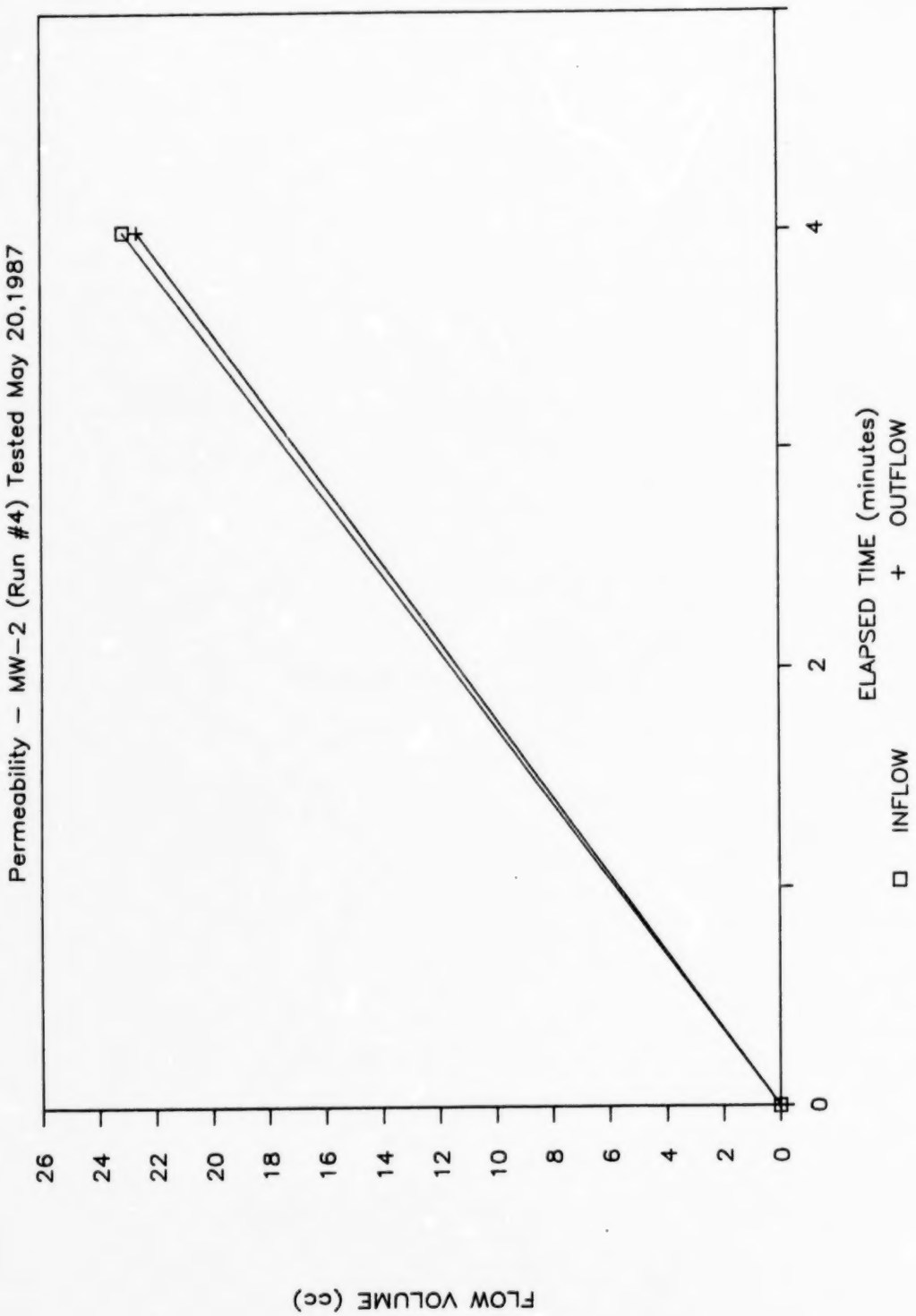
NOTES

Data by F.A.R.

Golder Associates

TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST
SHEET 2 OF 2

FIGURE 14-2



Golder Associates

TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 1 OF 2

FIGURE 15-1

BOREHOLE NUMBER — PROJECT 871-1159

SAMPLE NUMBER MW-2 (run #1-#4 inclusive)

Sample Tested May 27,1987 — Ontario Research Foundation /Tailings /Ontario

SAMPLE TYPE Cemented Tailings

ORIGINAL:	LENGTH cm	2.380	TESTED:	AREA cm2	10.35	WET WEIGHT gm	52.9
	DIAMETER cm	3.630		LENGTH cm	2.38	DRY WEIGHT gm	49.2
	AREA cm2	10.350		PRESSURE kPA	50.57	VOLUME WATER cc	3.7
	VOLUME cc	24.634	HYDRAULIC GRADIENT (p/l)		78.57		

WATER CONTENT initial %	2.98	SPECIFIC GRAVITY	2.550	POROSITY (initial) Vv/Vo %	21.68%
WATER CONTENT final %	10.80	VOLUME SOLIDS cc	19.294		
UNIT WEIGHT kN/m3	21.05	VOLUME VOIDS cc	5.340		
DRY UNIT WEIGHT kN/m3	20.46	VOID RATIO	0.277		
lb/ft3	130.22	SATURATION %	69.289		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value

PERMEABILITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Base kPa
68.9	18.3	0.0		18.33	1935.392	50.6	68.9

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	INFLOW Vc cc	INFLOW aVc cc	OUTFLOW Vc cc	OUTFLOW aVc cc	DAILY PERMEABILITY RESULTS INFLOW cm/s	OUTFLOW cm/s
87-05-27	08:51	0	0	9.00	0.0	23.50	0.0		
87-05-27	08:56	5.0	300.0	41.00	32.00	2.50	21.00	1.31E-04	8.61E-05
87-05-27	09:18	0.0	0.0	54.00	0.00	22.60	0.00		
87-05-27	09:28	10.0	600.0	76.20	22.20	0.60	22.00	4.55E-05	4.51E-05
87-05-27	09:29	0.0	0.0	76.20	0.00	24.20	0.00		
87-05-27	09:42	13.0	780.0	51.20	25.00	0.20	24.00	3.94E-05	3.78E-05
87-05-27	09:45	0.0	0.0	51.20	0.00	24.40	0.00		
87-05-27	09:59	14.0	840.0	27.00	24.20	0.30	24.10	3.54E-05	3.53E-05

COEFFICIENT of PERMEABILITY,k, cm/s

TOTAL FLOW

MINUTES		
42	INFLOW,k	2.51E-04
	OUTFLOW,k	2.04E-04
	AVERAGE,k	2.28E-04

PART 1

MINUTES			
14	INFLOW,k	3.54E-05	cm/s
	OUTFLOW,k	3.53E-05	cm/s
	AVERAGE,k	3.53E-05	cm/s

PART 2

MINUTES			
14	INFLOW,k	3.54E-05	cm/s
	OUTFLOW,k	3.53E-05	cm/s
	AVERAGE,k	3.53E-05	cm/s
AVERAGE,k USE FOR ANALYSES		3.53E-05	cm/s

NOTES

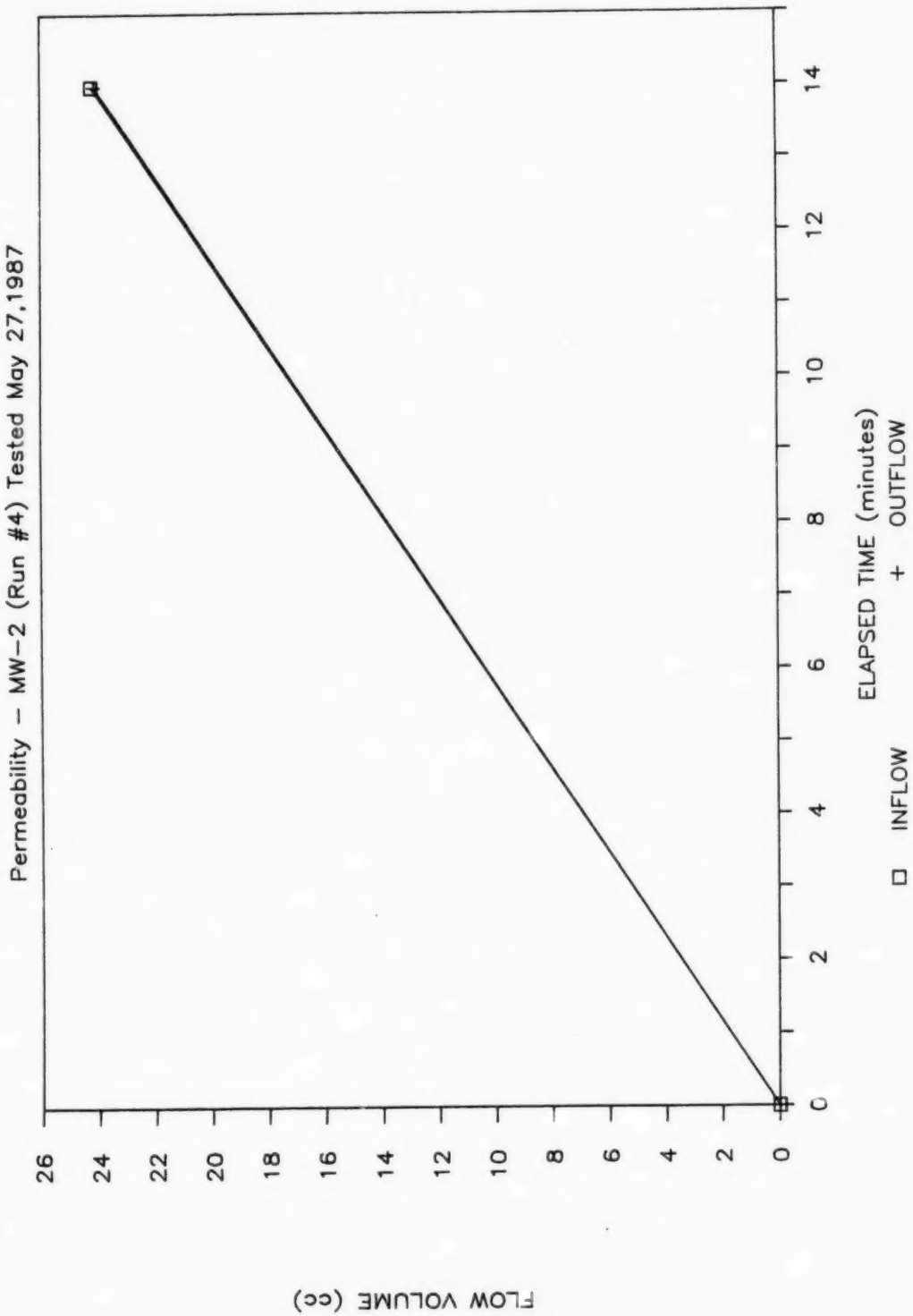
Data by F.A.R.

Golder Associates

TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 2 OF 2

FIGURE 15-2



Golder Associates

TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 1 OF 2

FIGURE 16-1

BOREHOLE NUMBER — PROJECT 871-1159

SAMPLE NUMBER P-5 (run #1-#3 inclusive)
Sample Tested May 20 to 21 ,1987 — Ontario Research Foundation /Tailings /Ontario

SAMPLE TYPE Cemented Tailings

ORIGINAL:	LENGTH cm	2.010	TESTED:	AREA cm2	11.05	WET WEIGHT gm	40.6
	DIAMETER cm	3.750		LENGTH cm	2.01	DRY WEIGHT gm	33.3
	AREA cm2	11.046		PRESSURE kPA	54.22	VOLUME WATER cc	7.3
	VOLUME cc	22.203	HYDRAULIC GRADIENT (p/l)		74.58		

WATER CONTENT initial %	21.90	SPECIFIC GRAVITY	2.380	POROSITY (initial) Vv/Vo %	34.79%
WATER CONTENT final %	19.80	VOLUME SOLIDS cc	14.478		
UNIT WEIGHT kN/m3	17.93	VOLUME VOIDS cc	7.724		
DRY UNIT WEIGHT kN/m3	14.71	VOID RATIO	0.533		
lb/ft3	93.63	SATURATION %	94.635		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value

PERMEABILITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Base kPa
68.9	14.7	0.0		14.68	1653.985	54.2	68.9

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	INFLOW Vc cc	INFLOW aVc cc	OUTFLOW Vc cc	OUTFLOW aVc cc	DAILY PERMEABILITY RESULTS INFLOW cm/s	OUTFLOW cm/s
87-05-20	09:20	0	0	61.00	0.0	24.40	0.0		
87-05-20	16:02	402.0	24120.0	60.20	0.80	23.00	1.40	4.03E-08	7.05E-08
87-05-21	08:59	0.0	0.0	57.10	0.00	20.10	0.00		
87-05-21	16:42	463.0	27780.0	55.00	2.10	17.70	2.40	9.19E-08	1.05E-07
87-05-22	08:59	0.0	0.0	53.20	0.00	12.70	0.00		
87-05-22	10:57	118.0	7080.0	53.10	0.10	12.20	0.50	1.72E-08	8.58E-08

COEFFICIENT of PERMEABILITY,k, cm/s

TOTAL FLOW

MINUTES		
983	INFLOW,k	1.49E-07
	OUTFLOW,k	2.61E-07
	AVERAGE,k	2.05E-07

NOTES

PART 1

MINUTES			
118	INFLOW,k	1.72E-08	cm/s
	OUTFLOW,k	8.58E-08	cm/s
	AVERAGE,k	5.15E-08	cm/s

PART 2

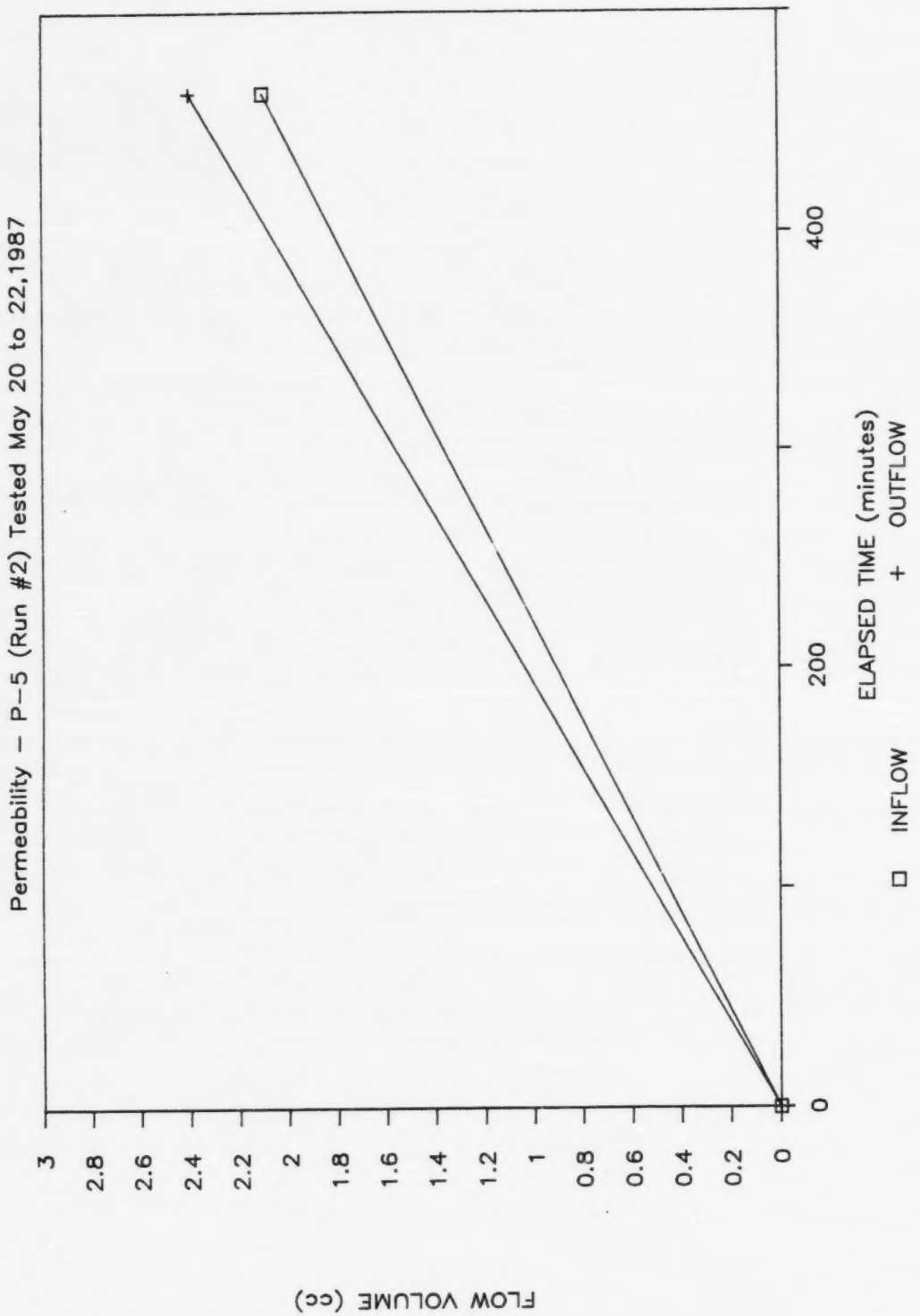
MINUTES			
118	INFLOW,k	1.72E-08	cm/s
	OUTFLOW,k	8.58E-08	cm/s
	AVERAGE,k	5.15E-08	cm/s
AVERAGE,k USE FOR ANALYSES		5.15E-08	cm/s

Data by F.A.R.

TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 2 OF 2

FIGURE 16-2



Golder Associates

TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 1 OF 2

FIGURE 17-1

BOREHOLE NUMBER — PROJECT 871-1159

SAMPLE NUMBER P-5 (run #1-#2 inclusive)

Sample Tested May 27 & 28 ,1997 — Ontario Research Foundation /Tailings /Ontario

SAMPLE TYPE Cemented Tailings

ORIGINAL: LENGTH cm	2.110	TESTED: AREA cm2	11.22	WET WEIGHT gm	44.1
DIAMETER cm	3.780	LENGTH cm	2.11	DRY WEIGHT gm	36.9
AREA cm2	11.223	PRESSURE kPA	50.57	VOLUME WATER cc	7.2
VOLUME cc	23.682	HYDRAULIC GRADIENT (p/l)	88.62		

WATER CONTENT initial %	19.60	SPECIFIC GRAVITY	2.300	POROSITY (initial) Vv/Vo %	32.25%
WATER CONTENT final %	16.30	VOLUME SOLIDS cc	16.043		
UNIT WEIGHT kN/m3	18.28	VOLUME VOIDS cc	7.638		
DRY UNIT WEIGHT kN/m3	15.28	VOID RATIO	0.476		
lb/ft3	97.27	SATURATION %	94.918		

SATURATION by BACK PRESSURE (achieved)

Cell Pressure kPa	Back Pressure kPa	Test Duration min	Volume Water cc	B Value

PERMEABILITY TEST CONDITIONS

Cell Pressure kPa	Head Pressure kPa	Back Pressure kPa	Volume Change cc	Effective Head Pressure kPa	Constant Ah	Effective Confining Pressure Top kPa	Base kPa
68.9	18.3	0.0		18.33	2098.638	50.6	68.9

DATE YY-MM-DD	CLOCK time	ELAPSED TIME min.	ELAPSED TIME sec.	INFLOW Vc cc	INFLOW aVc cc	OUTFLOW Vc cc	OUTFLOW aVc cc	DAILY PERMEABILITY RESULTS INFLOW cm/s	DAILY PERMEABILITY RESULTS OUTFLOW cm/s
87-05-27	08:54	0	0	49.30	0.0	23.50	0.0		
87-05-28	10:37	1543.0	92580.0	44.60	4.70	19.10	4.40	5.10E-08	4.79E-08
87-05-28	11:11	0.0	0.0	44.60	0.00	19.10	0.00		
87-05-28	19:03	472.0	28320.0	42.90	1.70	17.30	1.80	6.04E-08	6.39E-08

COEFFICIENT of PERMEABILITY,k, cm/s

TOTAL FLOW

MINUTES		
2015	INFLOW,k	1.11E-07
	OUTFLOW,k	1.12E-07
	AVERAGE,k	1.12E-07

NOTES

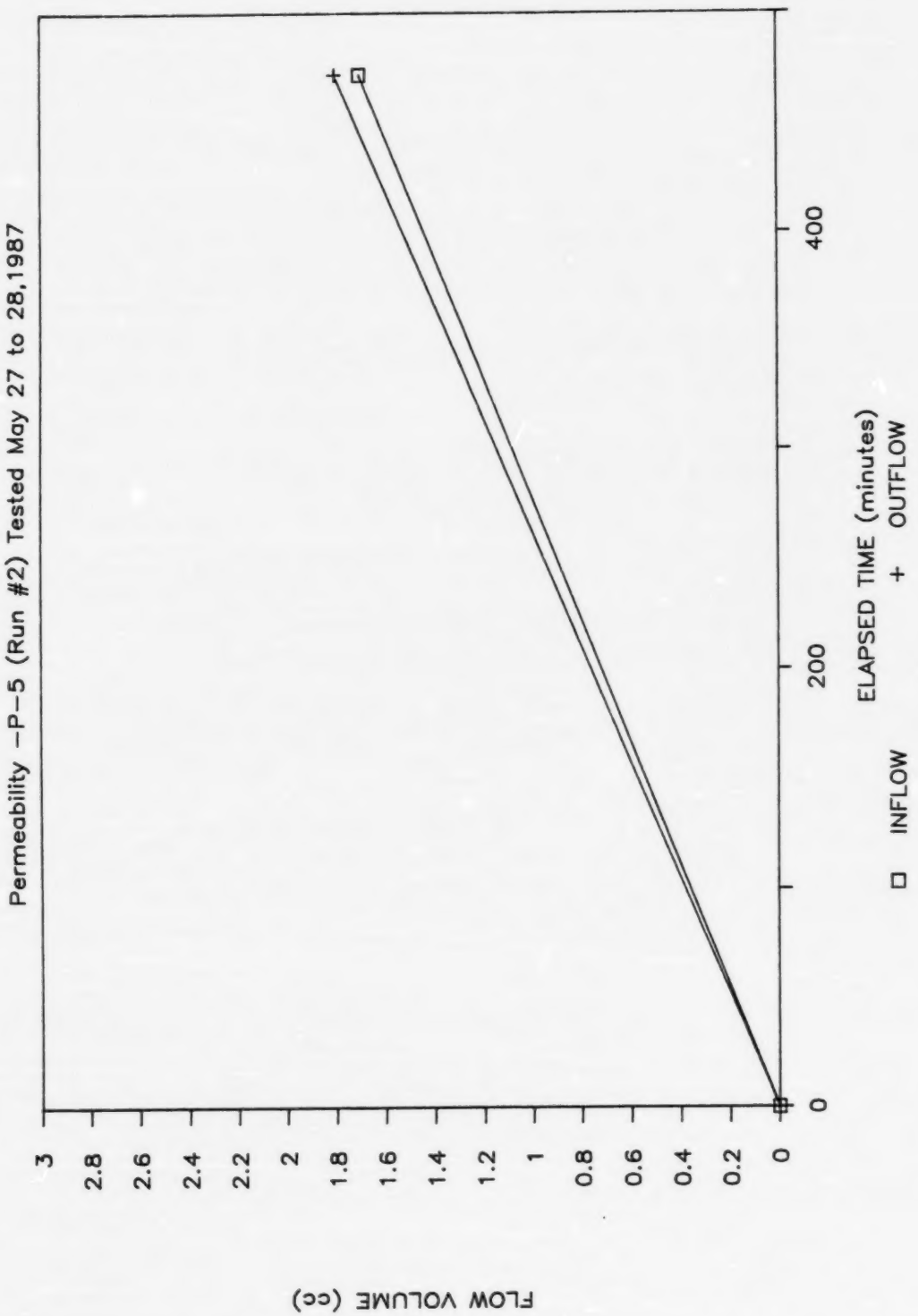
PART 1			
MINUTES	INFLOW,k	6.04E-08	cm/s
472	OUTFLOW,k	6.39E-08	cm/s
	AVERAGE,k	6.21E-08	cm/s
PART 2			
MINUTES	INFLOW,k	6.04E-08	cm/s
472	OUTFLOW,k	6.39E-08	cm/s
	AVERAGE,k	6.21E-08	cm/s
AVERAGE,k USE FOR ANALYSES		6.21E-08	cm/s

Data by F.A.R.

TRIAXIAL PERMEABILITY (CONSTANT HEAD) TEST

SHEET 2 OF 2

FIGURE 17-2



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UNDRAINED TRIAXIAL COMPRESSION (UU)

SHEET 1 OF 2

FIGURE 18-1

UNDRAINED TRIAXIAL COMPRESSION TEST (UU)

PROJECT NUMBER	871-1159	PROVING RING,kg/mm div.	0.266
SAMPLE NUMBER	KK-1-A	STRAIN RATE mm/min	1.3
CASTING DATE	30-04-87	SPECIFIC GRAVITY,measured	2.49
TESTING DATE	15-05-87	SA. KK-1-A	

SAMPLE HEIGHT,cm	6.52	WET WEIGHT,gm	109.6
SAMPLE DIAMETER,cm	3.14	DRY WEIGHT,gm	98.2
SAMPLE AREA,cm2	7.74	WATER CONTENT,%	11.6
SAMPLE VOLUME,cc	50.49	POROSITY,(Vv/Vo)	21.9
UNIT WEIGHT,kN/m3	21.28	DRY UNIT WT.,kN/m3	19.07

TEST RESULTS		LIQUID LIMIT,%	
COMPRESS.STRESS,kPa	2724.4	PLASTIC INDEX,%	
STRAIN AT FAILURE,%	2.9	LAB. VANE,Peak,kPa	
CELL PRESSURE,kPa	172.2	LAB. VANE,Resid.kPa	

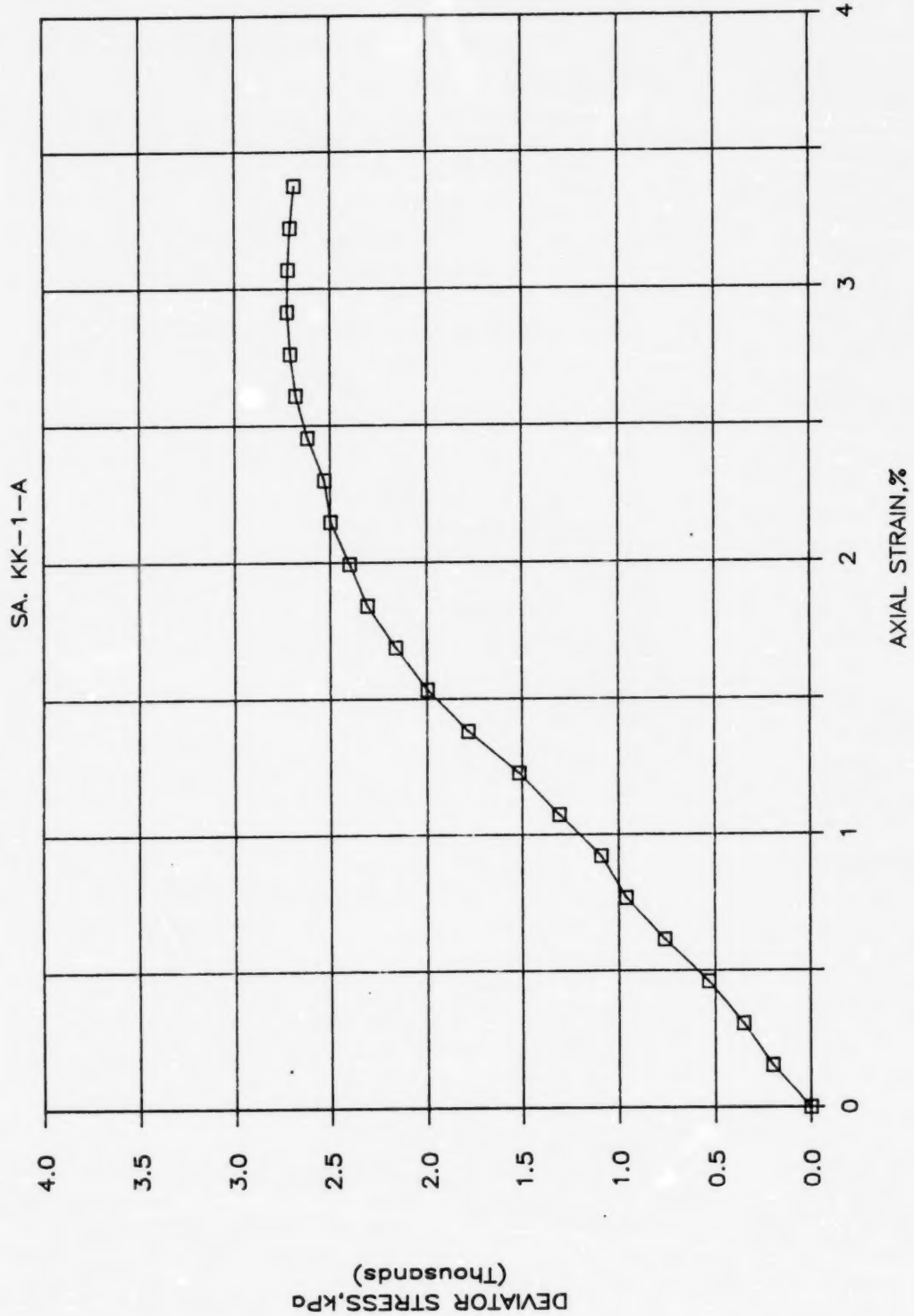
Strain Dial mm	Load Dial mm	Axial Strain %	Deviator Stress kPa
0.0	0.0	0	0.00
10.0	59.0	0.15	198.45
20.0	105.0	0.31	352.63
30.0	159.0	0.46	533.16
40.0	228.0	0.61	763.36
50.0	288.0	0.77	962.76
60.0	327.0	0.92	1091.44
70.0	392.0	1.07	1306.37
80.0	456.0	1.23	1517.30
90.0	537.0	1.38	1784.04
100.0	602.0	1.53	1996.88
110.0	653.0	1.69	2162.67
120.0	698.0	1.84	2308.10
130.0	727.0	1.99	2400.24
140.0	758.0	2.15	2498.68
150.0	769.0	2.30	2530.96
160.0	797.0	2.45	2619.00
170.0	817.0	2.61	2680.50
180.0	827.0	2.76	2709.04
190.0	833.0	2.91	2724.39
200.0	833.0	3.07	2720.08
210.0	831.0	3.22	2709.26
220.0	825.0	3.37	2685.43

PROJECT 871-1159 (ORF / Cemented Tailings / Ontario)

UNDRAINED TRIAXIAL COMPRESSION (UU)

SHEET 2 OF 2

FIGURE 18-2



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UNDRAINED TRIAXIAL COMPRESSION (UU)

SHEET 1 OF 2

FIGURE 19-1

UNDRAINED TRIAXIAL COMPRESSION TEST (UU)

PROJECT NUMBER	871-1159	PROVING RING,kg/mm div.	0.266
SAMPLE NUMBER	KK-1-B	STRAIN RATE mm/min	1.3
CASTING DATE	30-04-87	SPECIFIC GRAVITY,measured	2.49
TESTING DATE	15-05-87	SA. KK-1-B	

SAMPLE HEIGHT,cm	7.80	WET WEIGHT,gm	130.5
SAMPLE DIAMETER,cm	3.14	DRY WEIGHT,gm	116.3
SAMPLE AREA,cm2	7.74	WATER CONTENT,%	12.2
SAMPLE VOLUME,cc	60.40	POROSITY,(Vv/Vo)	22.7
UNIT WEIGHT,kN/m3	21.18	DRY UNIT WT.,kN/m3	18.88

TEST RESULTS		LIQUID LIMIT,%	
COMPRESS.STRESS,kPa	2142.2	PLASTIC INDEX,%	
STRAIN AT FAILURE,%	1.4	LAB. VANE,Peak,kPa	
CELL PRESSURE,kPa	344.5	LAB. VANE,Resid.kPa	

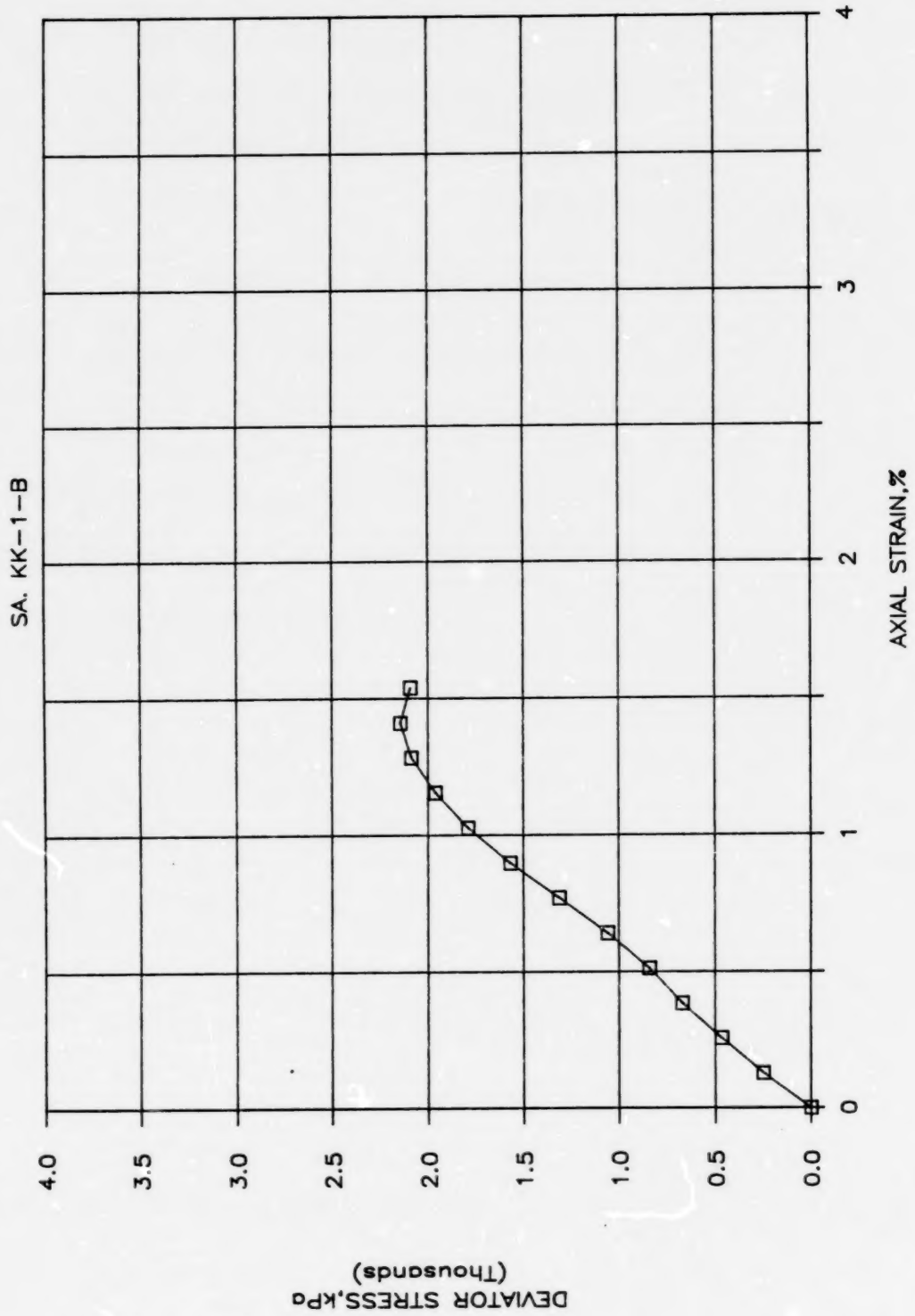
Strain Dial mm	Load Dial mm	Axial Strain %	Deviator Stress kPa
0.0	0.0	0	0.00
10.0	75.0	0.13	252.33
20.0	139.0	0.26	467.05
30.0	200.0	0.38	671.16
40.0	251.0	0.51	841.22
50.0	316.0	0.64	1057.70
60.0	392.0	0.77	1310.39
70.0	470.0	0.90	1569.10
80.0	537.0	1.03	1790.46
90.0	589.0	1.15	1961.29
100.0	627.0	1.28	2085.12
110.0	645.0	1.41	2142.20
120.0	630.0	1.54	2089.66

PROJECT 871-1159 (ORF / Cemented Tailings / Ontario)

UNDRAINED TRIAXIAL COMPRESSION (UU)

SHEET 2 OF 2

FIGURE 19-2



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UNDRAINED TRIAXIAL COMPRESSION (UU)

SHEET 1 OF 2

FIGURE 20-1

UNDRAINED TRIAXIAL COMPRESSION TEST (UU)

PROJECT NUMBER	871-1159	PROVING RING,kg/mm div.	0.266
SAMPLE NUMBER	KK-1-C	STRAIN RATE mm/min	1.3
CASTING DATE	30-04-87	SPECIFIC GRAVITY,measured	2.49
TESTING DATE	17-05-87	SA. KK-1-C	
SAMPLE HEIGHT,cm	7.14	WET WEIGHT,gm	117.7
SAMPLE DIAMETER,cm	3.14	DRY WEIGHT,gm	105.4
SAMPLE AREA,cm2	7.74	WATER CONTENT,%	11.7
SAMPLE VOLUME,cc	55.29	POROSITY,(Vv/Vo)	23.4
UNIT WEIGHT,kN/m3	20.88	DRY UNIT WT.,kN/m3	18.69
TEST RESULTS		LIQUID LIMIT,%	
COMPRESS.STRESS,kPa	2854.7	PLASTIC INDEX,%	
STRAIN AT FAILURE,%	3.9	LAB. VANE,Peak,kPa	
CELL PRESSURE,kPa	689.0	LAB. VANE,Resid.kPa	

Strain Dial mm	Load Dial mm	Axial Strain %	Deviator Stress kPa
0.0	0.0	0	0.00
10.0	19.0	0.14	63.92
20.0	22.0	0.28	73.90
30.0	70.0	0.42	234.92
40.0	114.0	0.56	381.88
50.0	161.0	0.70	538.57
60.0	221.0	0.84	738.24
70.0	293.0	0.98	977.36
80.0	350.0	1.12	1165.85
90.0	404.0	1.26	1343.82
100.0	461.0	1.40	1531.24
110.0	520.0	1.54	1724.76
120.0	574.0	1.68	1901.16
130.0	623.0	1.82	2060.51
140.0	665.0	1.96	2196.29
150.0	705.0	2.10	2325.07
160.0	735.0	2.24	2420.54
170.0	759.0	2.38	2496.00
180.0	780.0	2.52	2561.38
190.0	799.0	2.66	2620.00
200.0	817.0	2.80	2675.17
210.0	832.0	2.94	2720.36
220.0	844.0	3.08	2755.61
230.0	855.0	3.22	2787.49
240.0	864.0	3.36	2812.76
250.0	869.0	3.50	2824.93
260.0	874.0	3.64	2837.06
280.0	882.0	3.92	2854.71
300.0	881.0	4.20	2843.16
320.0	879.0	4.48	2828.41
340.0	877.0	4.76	2813.70

PROJECT 871-1159 (ORF / Cemented Tailings / Ontario)

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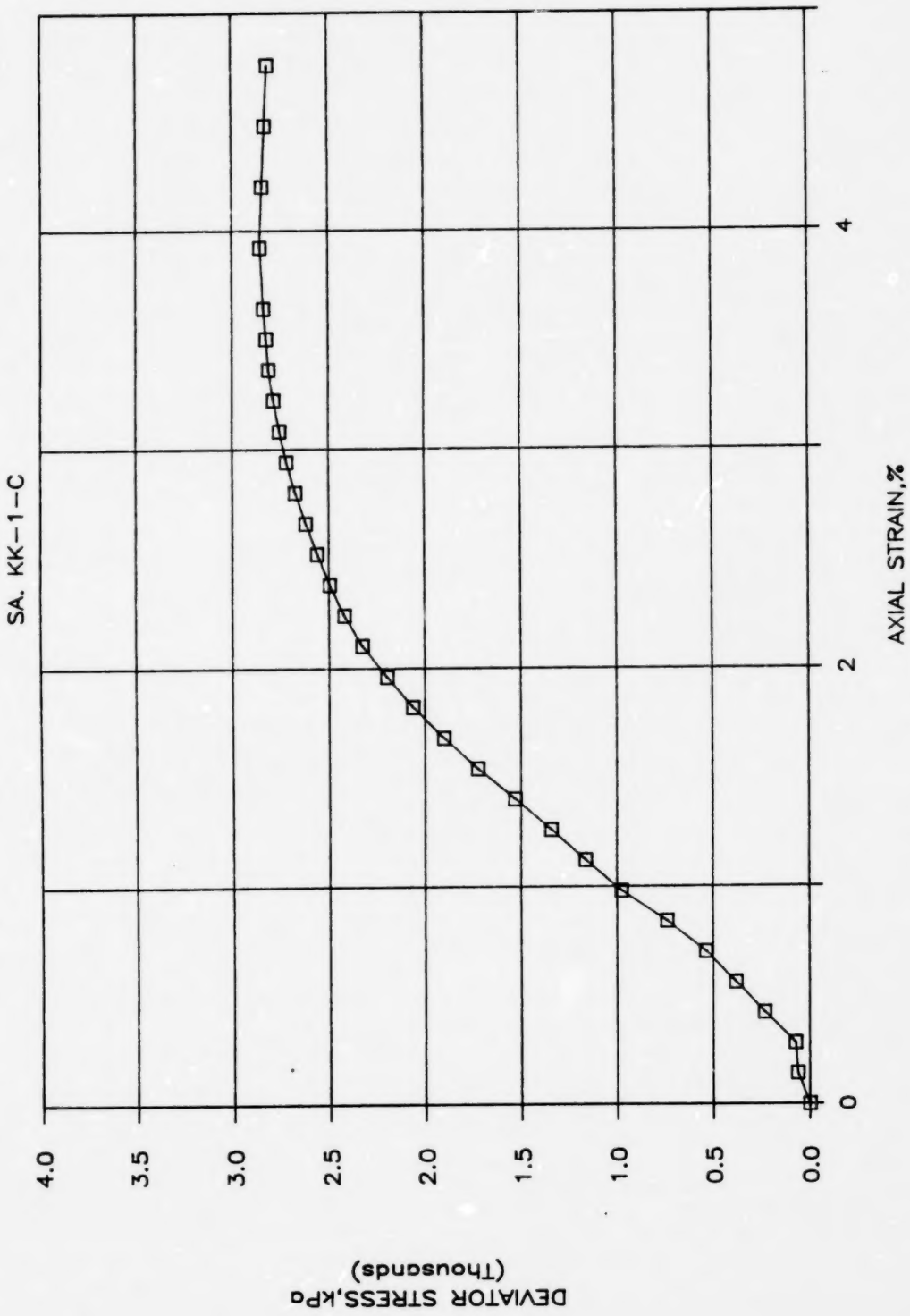
UNDRAINED TRIAXIAL COMPRESSION (UU)

SHEET 2 OF 2

FIGURE 20-2



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UNDRAINED TRIAXIAL COMPRESSION (UU)

SHEET 1 OF 2

FIGURE 21-1

UNDRAINED TRIAXIAL COMPRESSION TEST (UU)

PROJECT NUMBER	871-1159	PROVING RING,kg/mm div.	0.266
SAMPLE NUMBER	MW-2-A	STRAIN RATE mm/min	1.3
CASTING DATE	30-04-87	SPECIFIC GRAVITY,measured	2.54
TESTING DATE	15-05-87	SA. MW-2-A	

SAMPLE HEIGHT,cm	6.22	WET WEIGHT,gm	105.2
SAMPLE DIAMETER,cm	3.12	DRY WEIGHT,gm	86.9
SAMPLE AREA,cm2	7.65	WATER CONTENT,%	21.1
SAMPLE VOLUME,cc	47.55	POROSITY,(Vv/Vo)	28.1
UNIT WEIGHT,kN/m3	21.68	DRY UNIT WT.,kN/m3	17.91

TEST RESULTS		LIQUID LIMIT,%	
COMPRESS.STRESS,kPa	3312.8	PLASTIC INDEX,%	
STRAIN AT FAILURE,%	1.9	LAB. VANE,Peak,kPa	
CELL PRESSURE,kPa	172.2	LAB. VANE,Resid.kPa	

Strain Dial mm	Load Dial mm	Axial Strain %	Deviator Stress kPa
0.0	0.0	0	0.00
10.0	20.0	0.16	68.13
20.0	20.0	0.32	68.02
30.0	87.0	0.48	295.42
40.0	270.0	0.64	915.33
50.0	498.0	0.80	1685.55
60.0	639.0	0.96	2159.28
70.0	737.0	1.13	2486.39
80.0	817.0	1.29	2751.81
90.0	890.0	1.45	2992.80
100.0	964.0	1.61	3236.35
110.0	987.0	1.77	3308.15
120.0	990.0	1.93	3312.78
130.0	970.0	2.09	3240.53

PROJECT 871-1159 (ORF / Cemented Tailings / Ontario)

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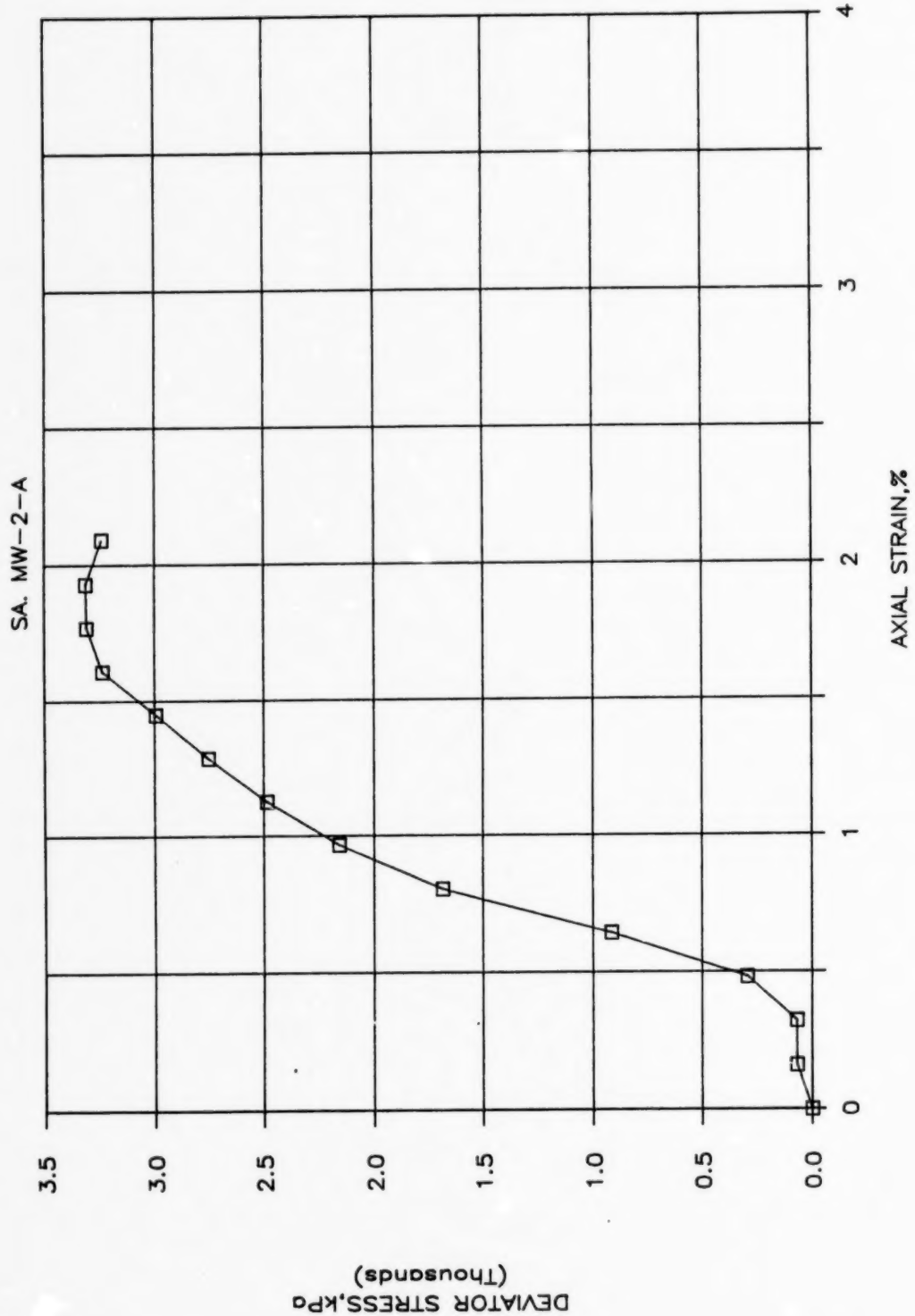
UNDRAINED TRIAXIAL COMPRESSION (UU)

SHEET 2 OF 2

FIGURE 21-2



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UNDRAINED TRIAXIAL COMPRESSION (UU)

SHEET 1 OF 2

FIGURE 22-1

UNDRAINED TRIAXIAL COMPRESSION TEST (UU)

PROJECT NUMBER	871-1159	PROVING RING,kg/mm div.	0.266
SAMPLE NUMBER	MW-2-B	STRAIN RATE mm/min	1.3
CASTING DATE	30-04-87	SPECIFIC GRAVITY,measured	2.54
TESTING DATE	15-05-87	SA. MW-2-B	

SAMPLE HEIGHT,cm	7.37	WET WEIGHT,gm	123.4
SAMPLE DIAMETER,cm	3.12	DRY WEIGHT,gm	111.8
SAMPLE AREA,cm2	7.65	WATER CONTENT,%	10.4
SAMPLE VOLUME,cc	56.35	POROSITY,(Vv/Vo)	21.9
UNIT WEIGHT,kN/m3	21.47	DRY UNIT WT.,kN/m3	19.45

TEST RESULTS		LIQUID LIMIT,%	
COMPRESS.STRESS,kPa	2577.4	PLASTIC INDEX,%	
STRAIN AT FAILURE,%	1.9	LAB. VANE,Peak,kPa	
CELL PRESSURE,kPa	344.5	LAB. VANE,Resid.kPa	

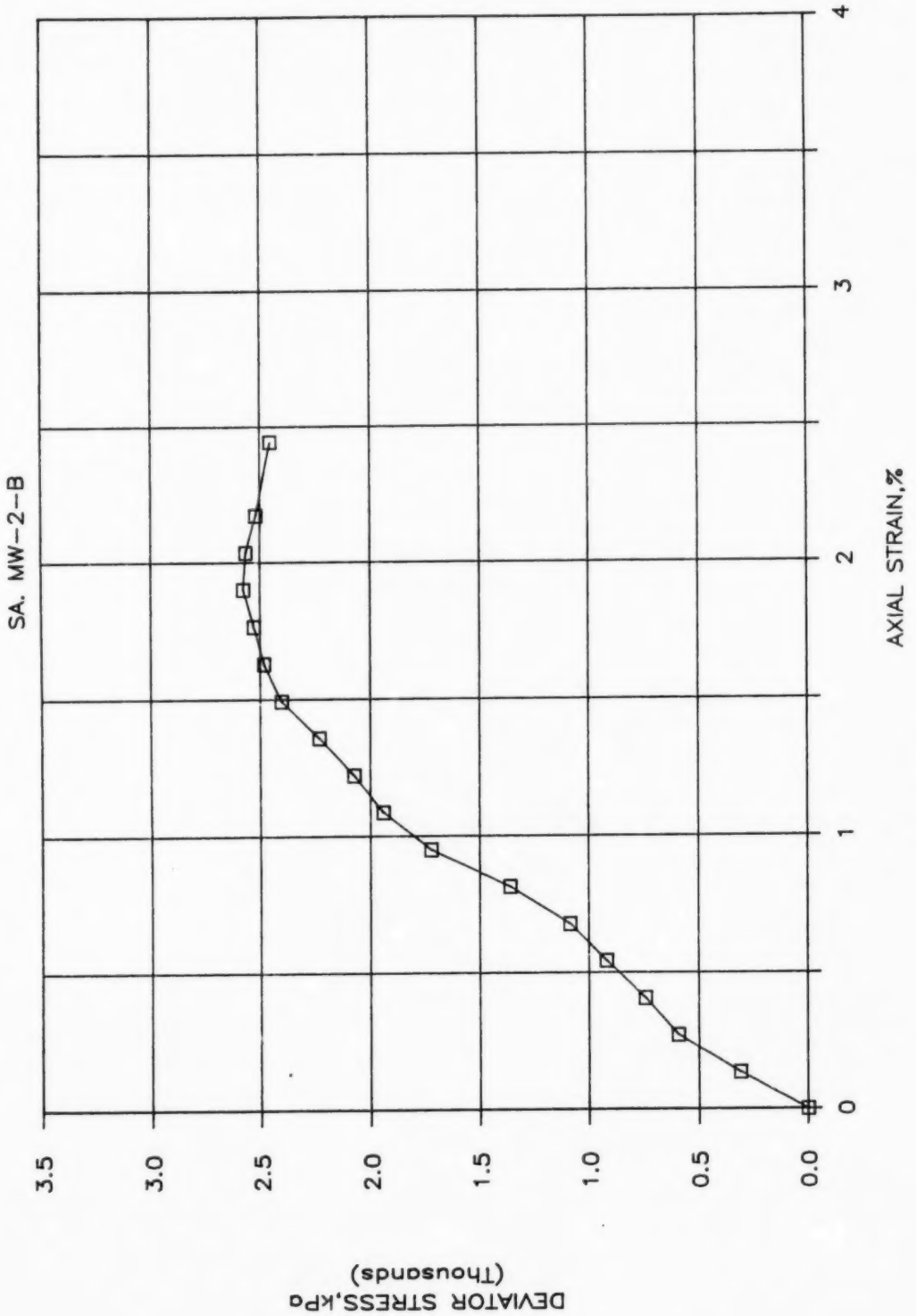
Strain Dial mm	Load Dial mm	Axial Strain %	Deviator Stress kPa
0.0	0.0	0	0.00
10.0	91.0	0.14	310.08
20.0	175.0	0.27	595.49
30.0	219.0	0.41	744.20
40.0	271.0	0.54	919.65
50.0	320.0	0.68	1084.45
60.0	402.0	0.81	1360.48
70.0	510.0	0.95	1723.63
80.0	575.0	1.09	1940.64
90.0	615.0	1.22	2072.80
100.0	663.0	1.36	2231.51
110.0	715.0	1.49	2403.22
120.0	740.0	1.63	2483.82
130.0	755.0	1.76	2530.67
140.0	770.0	1.90	2577.38
150.0	768.0	2.03	2567.13
160.0	755.0	2.17	2520.19
180.0	737.0	2.44	2453.28

PROJECT 871-1159 (ORF / Cemented Tailings / Ontario)

UNDRAINED TRIAXIAL COMPRESSION (UU)

SHEET 2 OF 2

FIGURE 22-2



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UNDRAINED TRIAXIAL COMPRESSION (UU)
SHEET 1 OF 2

FIGURE 23-1

UNDRAINED TRIAXIAL COMPRESSION TEST (UU)

PROJECT NUMBER	871-1159	PROVING RING,kg/mm div.	0.266
SAMPLE NUMBER	MW-2-C	STRAIN RATE mm/min	1.3
CASTING DATE	30-04-87	SPECIFIC GRAVITY,measured	2.54
TESTING DATE	17-05-87	SA. MW-2-C	

SAMPLE HEIGHT,cm	6.16	WET WEIGHT,gm	104.0
SAMPLE DIAMETER,cm	3.12	DRY WEIGHT,gm	94.2
SAMPLE AREA,cm2	7.65	WATER CONTENT,%	10.5
SAMPLE VOLUME,cc	47.10	POROSITY,(Vv/Vo)	21.2
UNIT WEIGHT,kN/m3	21.66	DRY UNIT WT.,kN/m3	19.61

TEST RESULTS		LIQUID LIMIT,%	
COMPRESS.STRESS,kPa	5241.9	PLASTIC INDEX,%	
STRAIN AT FAILURE,%	2.3	LAB. VANE,Peak,kPa	
CELL PRESSURE,kPa	689.0	LAB. VANE,Resid.kPa	

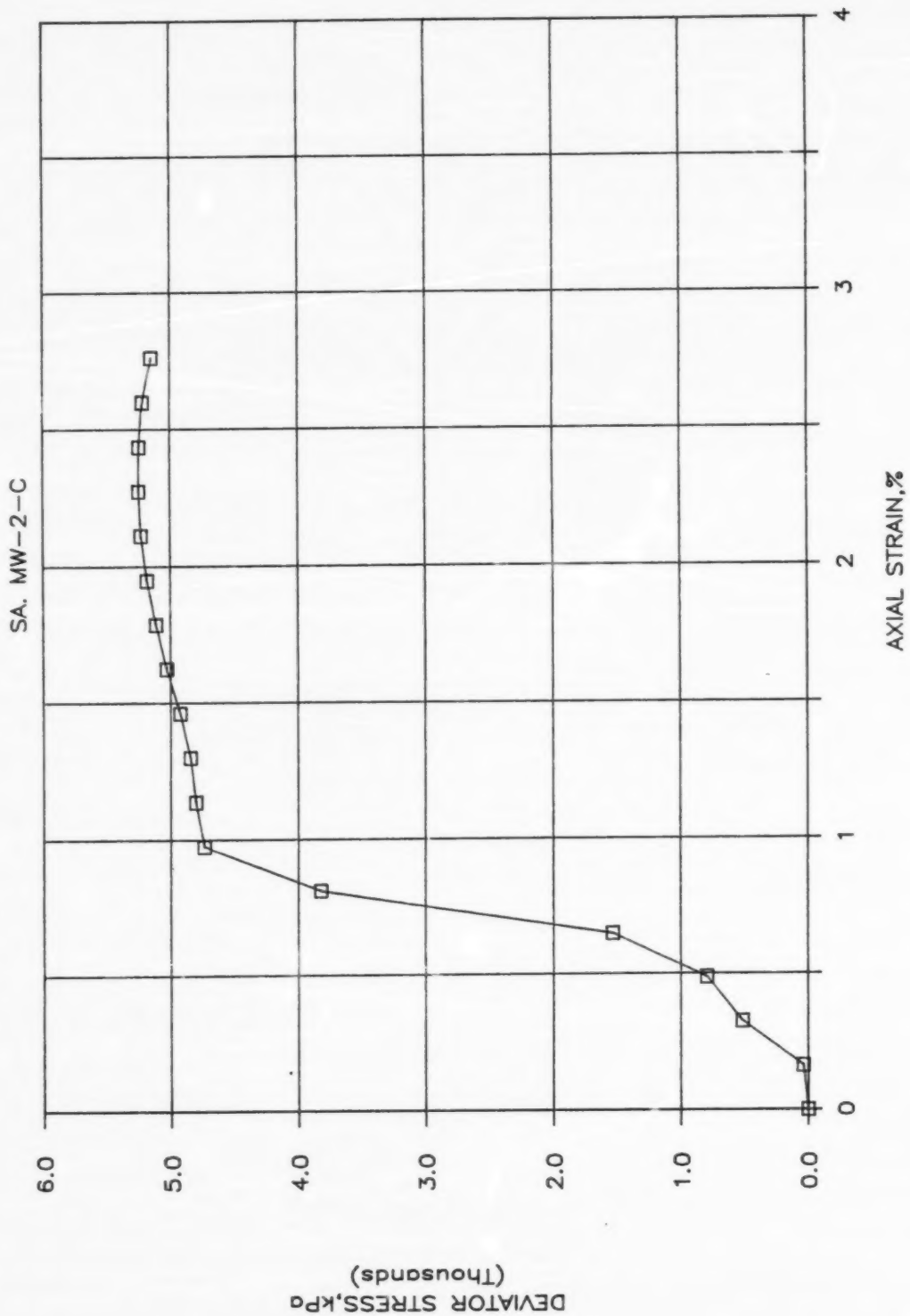
Strain Dial mm	Load Dial mm	Axial Strain %	Deviator Stress kPa
0.0	0.0	0	0.00
10.0	12.0	0.16	40.88
20.0	152.0	0.32	516.95
30.0	235.0	0.49	797.93
40.0	452.0	0.65	1532.24
50.0	1130.0	0.81	3824.34
60.0	1402.0	0.97	4737.12
70.0	1424.0	1.14	4803.57
80.0	1439.0	1.30	4846.20
90.0	1465.0	1.46	4925.65
100.0	1498.0	1.62	5028.30
110.0	1525.0	1.79	5110.49
120.0	1548.0	1.95	5178.99
130.0	1565.0	2.11	5227.19
140.0	1572.0	2.27	5241.87
150.0	1574.0	2.43	5239.82
160.0	1569.0	2.60	5214.48
170.0	1550.0	2.76	5142.75

PROJECT 871-1159 (ORF / Cemented Tailings / Ontario)

UNDRAINED TRIAXIAL COMPRESSION (UU)

SHEET 2 OF 2

FIGURE 23-2



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UNDRAINED TRIAXIAL COMPRESSION (UU)

SHEET 1 OF 2

FIGURE 24-1

UNDRAINED TRIAXIAL COMPRESSION TEST (UU)

PROJECT NUMBER	871-1159	PROVING RING,kg/mm div.	0.266
SAMPLE NUMBER	P-5-A	STRAIN RATE mm/min	1.3
CASTING DATE	30-04-87	SPECIFIC GRAVITY,measured	2.30
TESTING DATE	15-05-87	SA. P-5-A	

SAMPLE HEIGHT,cm	6.39	WET WEIGHT,gm	94.2
SAMPLE DIAMETER,cm	3.14	DRY WEIGHT,gm	82.6
SAMPLE AREA,cm2	7.74	WATER CONTENT,%	14.0
SAMPLE VOLUME,cc	49.48	POROSITY,(Vv/Vo)	27.4
UNIT WEIGHT,kN/m3	18.66	DRY UNIT WT.,kN/m3	16.36

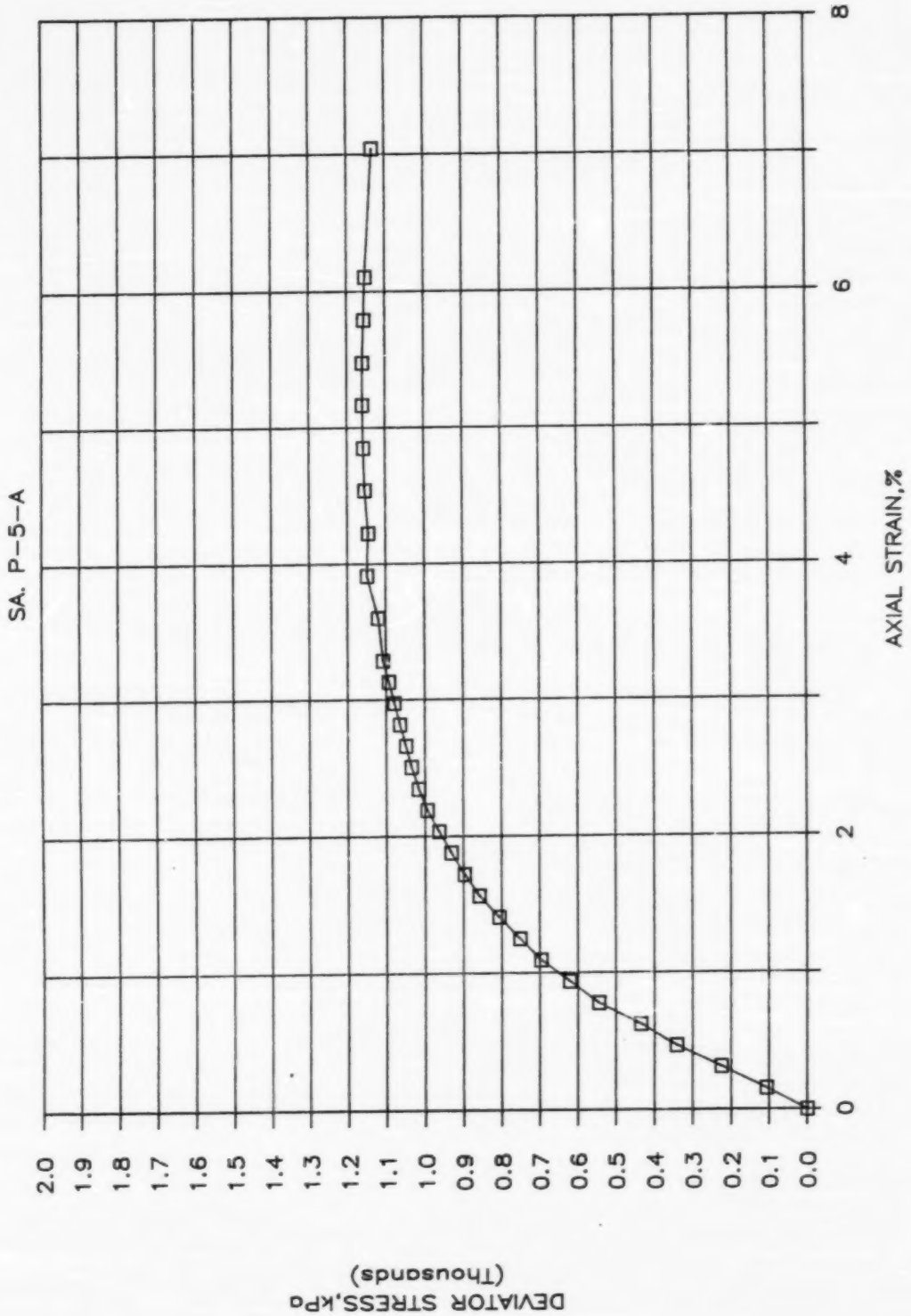
TEST RESULTS		LIQUID LIMIT,%	
COMPRESS.STRESS,kPa	1159.7	PLASTIC INDEX,%	
STRAIN AT FAILURE,%	5.2	LAB. VANE,Peak,kPa	
CELL PRESSURE,kPa	689.0	LAB. VANE,Resid.kPa	

Strain Dial mm	Load Dial mm	Axial Strain %	Deviator Stress kPa
0.0	0.0	0	0.00
10.0	32.0	0.16	107.63
20.0	67.0	0.31	225.00
30.0	102.0	0.47	342.00
40.0	130.0	0.63	435.19
50.0	163.0	0.78	544.81
60.0	186.0	0.94	620.70
70.0	209.0	1.09	696.35
80.0	226.0	1.25	751.80
90.0	243.0	1.41	807.07
100.0	259.0	1.56	858.85
110.0	271.0	1.72	897.21
120.0	282.0	1.88	932.14
130.0	292.0	2.03	963.66
140.0	302.0	2.19	995.07
150.0	309.0	2.35	1016.51
160.0	315.0	2.50	1034.58
170.0	320.0	2.66	1049.32
180.0	325.0	2.82	1064.00
190.0	330.0	2.97	1078.63
200.0	335.0	3.13	1093.21
210.0	340.0	3.29	1107.73
230.0	345.0	3.60	1120.38
250.0	355.0	3.91	1149.11
270.0	355.0	4.23	1145.37
290.0	359.0	4.54	1154.49
310.0	361.0	4.85	1157.12
330.0	363.0	5.16	1159.70
350.0	364.0	5.48	1159.06
370.0	364.0	5.79	1155.22
390.0	364.0	6.10	1151.38
450.0	362.0	7.04	1133.60

UNDRAINED TRIAXIAL COMPRESSION (UU)

SHEET 2 OF 2

FIGURE 24-2



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UNDRAINED TRIAXIAL COMPRESSION (UU)

SHEET 1 OF 2

FIGURE 25-1

UNDRAINED TRIAXIAL COMPRESSION TEST (UU)

PROJECT NUMBER	871-1159	PROVING RING,kg/mm div.	0.266
SAMPLE NUMBER	P-5-B	STRAIN RATE mm/min	1.3
CASTING DATE	30-04-87	SPECIFIC GRAVITY,measured	2.30
TESTING DATE	15-05-87	SA. P-5-B	

SAMPLE HEIGHT,cm	6.02	WET WEIGHT,gm	89.9
SAMPLE DIAMETER,cm	3.14	DRY WEIGHT,gm	78.2
SAMPLE AREA,cm2	7.74	WATER CONTENT,%	15.0
SAMPLE VOLUME,cc	46.62	POROSITY,(Vv/Vo)	27.1
UNIT WEIGHT,kN/m3	18.90	DRY UNIT WT.,kN/m3	16.44

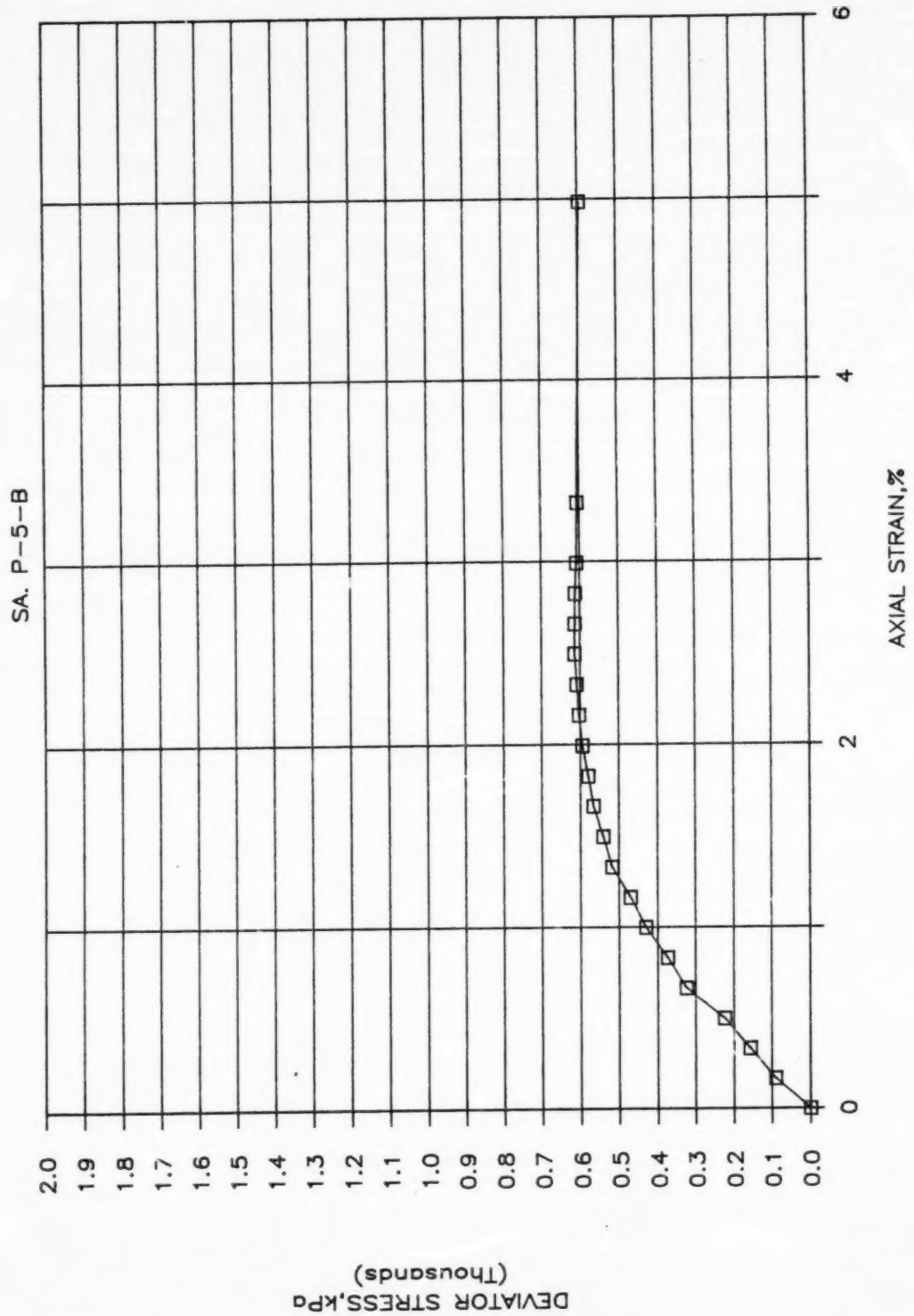
TEST RESULTS		LIQUID LIMIT,%	
COMPRESS.STRESS,kPa	614.3	PLASTIC INDEX,%	
STRAIN AT FAILURE,%	2.5	LAB. VANE,Peak,kPa	
CELL PRESSURE,kPa	344.5	LAB. VANE,Resid.kPa	

Strain Dial mm	Load Dial mm	Axial Strain %	Deviator Stress kPa
0.0	0.0	0	0.00
10.0	27.0	0.17	90.80
20.0	47.0	0.33	157.80
30.0	67.0	0.50	224.58
40.0	97.0	0.66	324.60
50.0	112.0	0.83	374.17
60.0	129.0	1.00	430.24
70.0	141.0	1.16	469.47
80.0	156.0	1.33	518.54
90.0	163.0	1.50	540.90
100.0	171.0	1.66	566.49
110.0	175.0	1.83	578.76
120.0	180.0	1.99	594.29
130.0	183.0	2.16	603.17
140.0	185.0	2.33	608.72
150.0	187.0	2.49	614.26
160.0	187.0	2.66	613.21
170.0	187.0	2.82	612.16
180.0	186.0	2.99	607.85
200.0	186.0	3.32	605.77
300.0	186.0	4.98	595.36

UNDRAINED TRIAXIAL COMPRESSION (UU)

SHEET 2 OF 2

FIGURE 25-2



UNDRAINED TRIAXIAL COMPRESSION (UU)
SHEET 1 OF 2

FIGURE 26-1

UNDRAINED TRIAXIAL COMPRESSION TEST (UU)

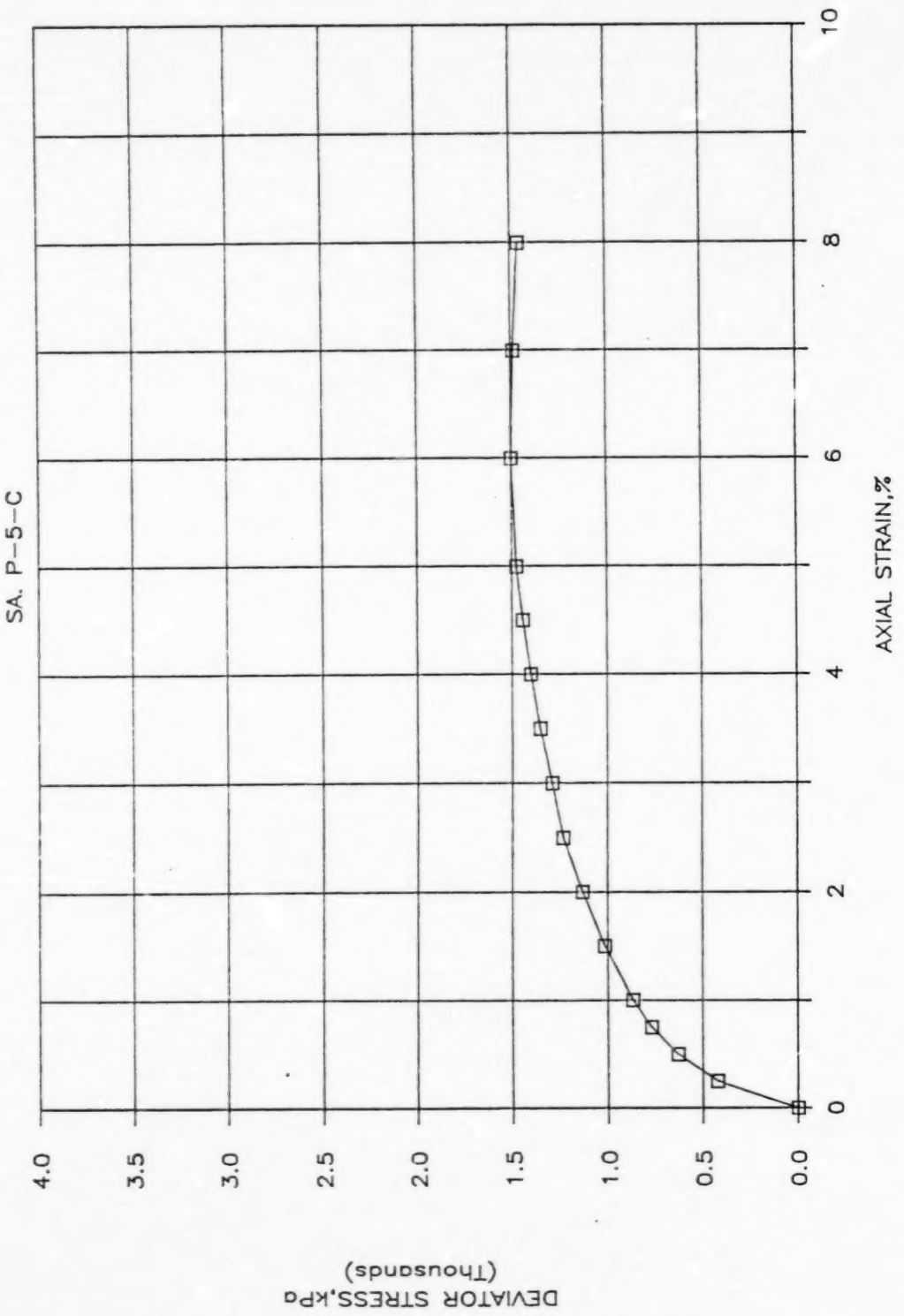
PROJECT NUMBER	871-1159	PROVING RING,kg/mm div.	0.266
SAMPLE NUMBER	P-5-C	STRAIN RATE mm/min	1.3
CASTING DATE	30-04-87	SPECIFIC GRAVITY,measured	2.30
TESTING DATE	15-05-87	SA. P-5-C	
SAMPLE HEIGHT,cm	6.01	WET WEIGHT,gm	89.1
SAMPLE DIAMETER,cm	3.07	DRY WEIGHT,gm	80.8
SAMPLE AREA,cm2	7.41	WATER CONTENT,%	10.3
SAMPLE VOLUME,cc	44.55	POROSITY,(Vv/Vo)	21.1
UNIT WEIGHT,kN/m3	19.61	DRY UNIT WT.,kN/m3	17.78
TEST RESULTS		LIQUID LIMIT,%	
COMPRESS.STRESS,kPa	1502.1	PLASTIC INDEX,%	
STRAIN AT FAILURE,%	6.0	LAB. VANE,Peak,kPa	
CELL PRESSURE,kPa	172.2	LAB. VANE,Resid.kPa	

Strain Dial mm	Load Dial mm	Axial Strain %	Deviator Stress kPa
0.0	0.0	0	0.00
15.0	120.0	0.25	421.29
30.0	180.0	0.50	630.35
45.0	220.0	0.75	768.50
60.1	249.0	1.00	867.60
90.1	293.0	1.50	1015.76
120.1	328.0	2.00	1131.34
150.1	360.0	2.50	1235.39
180.1	379.0	3.00	1293.93
210.1	399.0	3.50	1355.20
240.1	415.0	3.99	1402.25
270.1	430.0	4.49	1445.38
300.1	442.0	4.99	1477.95
360.2	454.0	5.99	1502.10
420.3	455.0	6.99	1489.39
480.4	451.0	7.99	1460.43

UNDRAINED TRIAXIAL COMPRESSION (UU)

SHEET 2 OF 2

FIGURE 26-2



Golder Associates